Eurasian Journal of Science and Environmental Education
2026, 6(2), 83-93
ISSN 2672-863X (Online)
https://www.ejsee.com/

Research Article

OPEN ACCESS

Teaching practicum and science education in European primary schools: A comparative analysis of pre-service teacher preparation across the EU

Konstantinos T. Kotsis [1]*

[1]Department of Primary Education, University of Ioannina, Ioannina, GREECE
***Corresponding Author:** kkotsis@uoi.gr

Citation: Kotsis, K. T. (2026). Teaching practicum and science education in European primary schools: A comparative analysis of pre-service teacher preparation across the EU. *Eurasian Journal of Science and Environmental Education*, 6(2), 83-93. https://doi.org/10.30935/ejsee/18494

ABSTRACT

The teaching practicum is fundamental to initial teacher education, providing pre-service teachers with opportunities to cultivate pedagogical skills in genuine classroom environments. This article offers a comparative analysis of the integration of science education within the teaching practicum for primary school pre-service teachers across 27 European Union (EU) member states. The study utilizes a qualitative comparative methodology, informed by policy documents, Eurydice reports, national teacher education frameworks, and academic literature, to analyze practicum structures, pedagogical orientations, and supervisory models. Countries are categorized into four regional clusters: Central and Northern, Southern, Western, and Eastern Europe, to discern convergent trends and divergences. Research indicates a widespread alignment towards comprehensive and organized practicum experiences throughout the EU, yet notable disparities exist in the integration of science education within these experiences. Central and Northern Europe demonstrate systematic, inquiry-driven integration bolstered by research-informed teacher education, while Southern and Eastern Europe encounter ongoing difficulties concerning mentor training, resource limitations, and conventional teaching methodologies. The analysis emphasizes how structural characteristics, the quality of mentoring, and university-school collaborations influence pre-service teachers' opportunities to cultivate science teaching competencies, providing a detailed comparative view of modern European teacher education.

Keywords: teaching practicum, pre-service teachers, science education, comparative education, European Union

Received: 25 Oct. 2025 ◆ Accepted: 15 Apr. 2026

INTRODUCTION

The teaching practicum is a fundamental element of pre-service primary teacher education, serving as a connection between academic studies and the practicalities of classroom experience. During the practicum, student teachers receive organized opportunities to observe seasoned educators, design and execute lessons, and engage in critical reflection on their instructional methodologies. In science education, the practicum assumes a crucial role: it is the setting where pedagogical content knowledge (PCK) is applied, inquiry-based teaching strategies are evaluated, and genuine interactions with students' scientific thinking are encountered. Consequently, effective practicum experiences are essential for cultivating confident and proficient future science educators (Abell, 2007; Nilsson, 2008; Osborne, 2013).

In the past twenty years, teacher education systems within the European Union (EU) have experienced significant reforms influenced by the Bologna process, the creation of the European higher education area (EHEA), and ongoing European Commission policy frameworks regarding education and training. These reforms aim to foster structural convergence in teacher education by implementing extended practicum durations, strengthening university-school collaborations, and enhancing quality assurance, all while preserving the autonomy of national education systems (European Commission, 2019; Eurydice, 2021). Simultaneously, science education has garnered heightened focus within European educational discussions, propelled by apprehensions regarding scientific literacy, the development of the STEM

workforce, and democratic engagement (Osborne, 2023). Recent empirical studies indicate that primary school students exhibit varying degrees of scientific literacy, underscoring the necessity for enhanced teacher preparation via practicum-based science education (Tsoumanis et al., 2024). The incorporation of science education into the teaching practicum is not simply a curricular aspect but a manifestation of how national systems implement European goals in the training of future educators.

Notwithstanding the common policy frameworks, significant discrepancies remain among EU member states regarding the structuring of the practicum and the integration of science education within it. Certain countries have formalized extensive, research-based practicum experiences that explicitly integrate inquiry-driven science instruction. Nonetheless, some persist in regarding science as a peripheral subject in primary education, leading to practicum experiences that offer scant opportunities for pre-service teachers to cultivate specialized competencies in science instruction (Appleton, 2003; Osborne, 2013). Comprehending these variations necessitates a systematic comparative analysis that considers both structural elements, such as the length and organization of practicum placements, and pedagogical orientations, including the characteristics of mentoring and the congruence between coursework and school practice.

This study analyzes the incorporation of science education into the teaching practicum for primary pre-service teachers in the 27 EU member states. The study categorizes the data into four regional clusters (Central and Northern, Southern, Western, and Eastern Europe) to discern patterns of convergence and divergence in practicum structures, supervisory frameworks, and pedagogical focuses. The objective is to provide a detailed comprehension of how national strategies mirror, adjust, or deviate from overarching European priorities in teacher education and scientific literacy. This analysis establishes a basis for evidence-based policy discussions and the formulation of targeted strategies to enhance science education during the practicum phase across various European contexts.

THEORETICAL AND POLICY FRAMEWORK

Comprehending the integration of science education within pre-service teachers' practicum experiences necessitates a dual theoretical perspective: one that examines the learning processes of teachers in practice, and another that reflects on the overarching European policy framework influencing teacher education and science instruction. These viewpoints establish the basis for the comparative analysis conducted in this study.

Teacher learning during the practicum is predominantly understood through the perspective of situated learning theory (Lave & Wenger, 1991), which conceptualizes learning as engagement in communities of practice. From this viewpoint, pre-service teachers cultivate professional knowledge not solely through theoretical application, but by engaging in genuine teaching contexts, where they observe, implement, and reflect on classroom interactions within a socially mediated framework. The practicum is not merely a training activity; it is a pivotal context for the development of professional identity, where pedagogical dispositions and classroom practices are cultivated (Korthagen, 2017; Zeichner, 2010). Situated learning in science education emphasizes the necessity of offering pre-service teachers substantial opportunities to create and execute inquiry-based science lessons, observe seasoned practitioners, and obtain feedback that fosters the enhancement of PCK (Abell, 2007; Nilsson, 2008).

The notion of PCK (Shulman, 1987) is especially pertinent to comprehending the function of science education in the practicum. PCK denotes the distinctive body of knowledge that educators cultivate at the convergence of content expertise and instructional methodologies. It encompasses the capacity to foresee students' misconceptions, select suitable representations, and support inquiry-based learning. Research in science education has consistently shown that PCK is most effectively cultivated in genuine classroom environments, where pre-service teachers engage with actual student responses and classroom dynamics (Friedrichsen et al., 2011; Kind, 2009). Multiple studies indicate that misconceptions in physics, particularly in mechanics and forces, persist among university students, underscoring the necessity for early and effectively structured interventions in teacher education (Stylos et al., 2008). A crucial element of developing PCK is the identification and rectification of students' misconceptions, especially in domains like thermal physics, where validated diagnostic instruments have demonstrated persistent alternative conceptions among university students (Stylos et al., 2021). Practicum experiences lacking in science instruction, or that diminish the role of science in overall teaching practice, can significantly hinder the cultivation of specialized PCK in this area, resulting in enduring deficits in confidence and efficacy when teachers commence their careers (Appleton, 2003; Nilsson, 2008).

In conjunction with these theoretical considerations, the European policy landscape significantly influences national practicum frameworks. Since the early 2000s, the Bologna process and the EHEA have promoted the standardization of teacher education programs through the alignment of degree structures, quality assurance protocols, and enhanced university-school collaborations. The European Commission has bolstered these reforms through communications that highlight the significance of science education and scientific literacy as essential competencies for economic innovation, sustainable development, and democratic citizenship (European Commission, 2015, 2019). The updated European reference framework of key competences for lifelong learning emphasizes "scientific literacy and comprehension of the natural world" as vital transversal competencies to be cultivated from primary education onward (European

Commission, 2019). These frameworks have shaped national teacher education curricula by advocating extended and more organized practicum durations, clearly defined learning outcomes for science education, and the incorporation of inquiry-based pedagogies in accordance with EU objectives for STEM education (Eurydice, 2021).

Notwithstanding these common frameworks, national systems demonstrate considerable variation in their interpretation and execution of European directives. Some countries have integrated their practicum frameworks with research-oriented methodologies that prioritize inquiry and reflective practice, while others continue to uphold conventional, discipline-general methods that regard science as a peripheral subject. This divergence illustrates variations in teacher education traditions, governance frameworks, resource distribution, and the emphasis placed on science within primary education. This article's comparative analysis is positioned at the convergence of theoretical insights into teacher learning and the policy frameworks that influence institutional practices across European contexts.

METHODOLOGY OF THE COMPARATIVE ANALYSIS

This study employs a qualitative comparative methodology to examine the integration of science education within the teaching practicum for pre-service primary teachers in the 27 member states of the EU. Comparative methodologies are adept at analyzing teacher education systems as they facilitate a systematic investigation of structural and pedagogical differences across various national contexts, while recognizing patterns of convergence influenced by common policy frameworks (Bray et al., 2014). This analysis examines how national teacher education systems interpret and implement EU-level frameworks regarding practicum design and priorities in science education.

The research employs documentary analysis as its principal data collection method. The documentary corpus analyzed in this study consisted of official policy and regulatory documents published mainly between 2010 and 2023, a period corresponding to the consolidation of Bologna process reforms and the implementation of updated European frameworks for teacher education and key competences. The sources included:

(a) national teacher education standards and accreditation frameworks issued by ministries of education or national agencies,

(b) official practicum regulations and guidelines defining the structure, duration, and assessment of school placements;

(c) national primary curriculum frameworks, with particular attention to science education,

(d) Eurydice comparative reports and country profiles on teacher education systems (Eurydice, 2021), and

(e) European Commission communications and policy documents related to science education, STEM, and key competences (European Commission, 2019).

Only official and publicly available documents were included in order to ensure comparability, reliability, and policy relevance across countries. These documents were selected because they define the formal expectations, structures, and priorities governing the teaching practicum and the positioning of science education within initial teacher preparation across EU member states. These sources were augmented by peer-reviewed studies concentrating on practicum design, inquiry-based science education (IBSE), and the professional development of primary educators within European contexts (Osborne, 2013, 2023).

The data analysis was conducted in three phases. Initially, the gathered documents were methodically categorized based on practicum structure (timing, duration, and placement models), pedagogical orientation (explicit integration of science education, inquiry-based methods), and supervision models (mentoring arrangements and university-school collaboration). The categories were formulated both deductively, based on established comparative education frameworks (Alexander, 2001; Bray et al., 2014), and inductively, through iterative analysis of the data.

During the second phase, nations were categorized into four regional clusters: Central and Northern Europe, Southern Europe, Western Europe, and Eastern Europe. This regional clustering illustrates historical, cultural, and institutional trends in teacher education throughout the continent, facilitating substantive comparative analysis without reductionism. The regional consortium adheres to standardized classifications employed in European educational research and policy evaluation (Eurydice, 2022).

In the third stage, the analysis concentrated on discerning patterns of convergence and divergence within and among these clusters. Convergence was defined as the existence of analogous structural or pedagogical characteristics across various national systems, especially when aligned with EU policy priorities. Divergence indicated substantial disparities in practicum design or the integration of science education, notwithstanding common frameworks. This dual focus facilitated the creation of a comparative typology that encompasses both structural tendencies and pedagogical particularities.

This methodological approach offers two significant advantages. It facilitates the amalgamation of policy analysis and pedagogical interpretation, acknowledging that teacher education systems are concurrently influenced by transnational policy frameworks and national pedagogical traditions. Secondly, it offers a systematic approach to analyze the function of science education in practicum experiences, a facet frequently overlooked in comparative teacher education studies (Hudson & Meyer, 2011; Vangrieken et al., 2017). The methodology is interpretive,

focusing on mapping patterns, relationships, and contexts instead of generating quantitative indicators.

COMPARATIVE ANALYSIS ACROSS EU COUNTRIES

The comparative analysis indicates notable structural similarities and pedagogical differences in how EU member states incorporate science education into the practicum experiences of pre-service primary teachers. Although the majority of countries have conformed to EU policy priorities by prolonging practicum duration and enhancing university-school collaborations, the degree and characteristics of science education integration differ significantly across regions. This section analyzes these patterns across four regional clusters: Central and Northern Europe, Southern Europe, Western Europe, and Eastern Europe.

Central and Northern Europe

Central and Northern European countries, such as Finland, Sweden, Denmark, the Netherlands, Germany, Austria, and Belgium, are distinguished by extensive, research-based practicum frameworks that frequently span several years of teacher education. These systems generally incorporate science education methodically within both academic coursework and practical training. In these contexts, pre-service teachers are required to develop and execute inquiry-based science lessons, engage in reflective practice through organized mentoring, and connect their classroom experiences to university-led seminars (Jakku-Sihvonen & Niemi, 2006; Jorde & Dillon, 2012).

Finland exemplifies a paradigmatic case. The Finnish model is based on research-informed teacher education, featuring prolonged practicum phases lasting three to four years. Pre-service teachers deliver science lessons under the supervision of seasoned mentor teachers, who are qualified educators affiliated with universities. This dual role fortifies the university-school connection, facilitating genuine incorporation of scientific inquiry methodologies (Ahtee, 2000; Juuti & Lavonen, 2016). Likewise, Sweden and Denmark prioritize reflective practice and collaborative inquiry, with pre-service teachers participating in co-planning and co-teaching of science curricula. The Netherlands incorporates science through thematic and interdisciplinary practicum projects, prompting educators to link scientific concepts to wider societal and environmental concerns (Alake-Tuenter, 2020).

Mentoring in this region is typically organized and specialized, with mentors undergoing formal training and frequently participating in teacher education research. The professionalization of mentoring is essential for enhancing PCK in science education (Friedrichsen et al., 2011; Kind, 2009).

Southern Europe

Southern European nations, such as Greece, Italy, Spain, and Portugal, have significantly enhanced the duration of practicums over the past twenty years; however, obstacles persist in the systematic integration of science education within these practicum experiences. In this region, practicum structures typically feature block placements in the latter stages of the degree program, with minimal incorporation of science-specific objectives during the earlier phases (García-Carmona & Zubimendi, 2020; Kallery et al., 2009).

In Greece, pre-service primary teachers generally undertake two to three practicum placements; however, science education is not uniformly emphasized in these experiences. The focus is primarily on general classroom management and literacy, while science lessons are occasionally regarded as optional or secondary activities. Despite the introduction of a new national science curriculum based on inquiry-based learning principles, its implementation in practicum settings is inconsistent and largely contingent upon mentor teachers and the prevailing school culture (Kotsis et al., 2025). Consequently, numerous pre-service teachers express diminished self-efficacy concerning their capacity to instruct physics and other scientific disciplines, a conclusion corroborated by empirical studies evaluating the efficacy beliefs of Greek pre-service teachers in physics education (Stylos et al., 2023). Italy and Spain display analogous trends; however, there is an increasing interest in implementing inquiry-based science modules during practicum, primarily motivated by EU-funded innovation initiatives rather than comprehensive policy reforms (Eurydice, 2022). Portugal has incorporated science more systematically via interdisciplinary thematic instruction; however, the lack of specialized mentor training hinders further integration.

Southern Europe exemplifies structural convergence accompanied by pedagogical lag: although practicum durations have increased in accordance with EU recommendations, science education frequently remains peripheral in actual teaching practices. Mentoring is generally less specialized, and opportunities for inquiry-based science instruction are largely contingent upon specific school contexts rather than national standards.

Western Europe

Western European nations, including France, Luxembourg, and Ireland, occupy an intermediary position between the Northern/Central and Southern clusters. Their practicum frameworks are institutionally sound, featuring clearly delineated collaborations between universities and schools; however, the degree of science integration fluctuates based on national curricular priorities.

In France, practicum experiences are integrated into the Master Métiers de l'Enseignement, de l'Éducation et de la Formation program, which encompasses academic coursework and school placements over a two-year period.

Science education garners moderate focus, featuring specific modules on scientific reasoning and pedagogy. The number of science lessons delivered during practicum may be restricted by curriculum limitations in primary schools (Delclaux & Saltiel, 2013). Luxembourg's multilingual and interdisciplinary curriculum incorporates science via cross-curricular inquiry projects, enabling pre-service teachers to investigate environmental and technological topics. Ireland prioritizes professional reflection, and recent curriculum reforms aim to improve science education through STEM-oriented practicum initiatives (Department of Education, 2019; Government of Ireland, 2023).

Western Europe exhibits balanced structures yet heterogeneous implementation, reflecting national curricular priorities rather than structural constraints. Mentoring is becoming more professionalized, yet it lacks universal specialization in science, resulting in inconsistent practicum experiences.

Eastern Europe

Eastern European nations, such as Poland, Hungary, the Czech Republic, Slovakia, Romania, Bulgaria, and the Baltic states, are experiencing incremental changes in their teacher education systems, shaped by EU accession and harmonization initiatives. Practicum structures have been expanded and formalized; however, the integration of science education remains inconsistent, frequently attributed to resource limitations and conventional pedagogical methods (Eurydice, 2022; Silova, 2010).

In numerous instances, science is regarded as a generalist discipline, and pre-service educators are not consistently mandated to instruct science lessons during their practicum. In Romania and Bulgaria, the practicum primarily emphasizes literacy and mathematics, while science is predominantly taught through university lectures rather than practical classroom experiences. Poland and Estonia have achieved notable advancements by incorporating inquiry-based science modules and promoting mentor teachers to facilitate the execution of science lessons (Kapanadze & Eilks, 2014). Nevertheless, mentoring systems in the region are frequently inadequately developed, and mentor training is seldom specialized. Eastern Europe exemplifies a region of structural alignment lacking comprehensive pedagogical integration, underscoring the significance of institutional capacity, mentor training, and curriculum reform in converting EU-level frameworks into effective practicum experiences.

The comparative results outlined above are encapsulated in **Table 1**, which offers a systematic overview of the teaching practicum for pre-service primary educators in science education across all EU member states. **Table 1** delineates essential characteristics based on six analytical dimensions:

Table 1. Comparative overview of teaching practicum for science education in primary schools across EU member states

Country	Practicum structure & duration	Content focus & pedagogical goals	Integration of science education	Supervisory models & partnerships	Assessment & reflection	Innovation & policy orientation
Austria	Structured practicum across bachelor's-master's; moderate duration	Balanced between general pedagogy and interdisciplinary content	Science embedded in Sachunterricht	Strong mentor role; variable science expertise	Structured reflections; mentor feedback	Gradual adoption of inquiry-based approaches
Belgium	Extended practicum throughout the program	Thematic integration, STEM emphasis increasing	Integrated science teaching modules	Collaborative university-school partnerships	Reflective journals and performance evaluation	Active STEM initiatives, uneven mentor preparation
Bulgaria	Practicum extended post-EU accession; limited duration	Emphasis on classroom management	Science integration is weak; dependent on mentor	Limited mentor training	Basic assessment	Policy reforms are ongoing; infrastructure limits innovation
Croatia	Moderate practicum duration	General pedagogy focus	Science is marginal in the practicum	Developing partnerships	Formal assessment with limited feedback	Policy alignment with EU frameworks
Cyprus	Practicum in later years; moderate duration	Curriculum-focused	Basic science lesson implementation required	University tutors coordinate with schools	Reflection reports	Gradual introduction of inquiry-based approaches
Czech Republic	Extended practicum phases post-Bologna	Content emphasis growing	Traditional science methods prevail	Mentor involvement varies	Portfolio and seminar-based reflection	Slow shift toward IBSE
Denmark	Sustained practicum from early years	Emphasis on scientific literacy and sustainability	Strong integration of inquiry-based science	Institutionalized partnerships; mentor training	Structured feedback and peer reflection	Innovation in thematic STEM teaching
Estonia	Extended practicum embedded in research-based model	Balanced content and pedagogy	Strong emphasis on inquiry-based science	Mentor training structured; good university links	Reflective assignments and assessment rubrics	Aligned with EU STEM and digital strategies
Finland	Extensive practicum (20-25 weeks), early start	Research-based pedagogy central	Systematic inquiry-based science teaching required	University-affiliated training schools	Structured, research-based reflection	Model system for science practicum innovation
France	Practicum during master's phase; alternation with coursework	National curriculum focus	Mandatory science teaching, uneven mentor expertise	Structured, but mentor quality varies	Written reports and mentor evaluation	Hybrid implementation of IBSE

Table 1 (Continued).

Country	Practicum structure & duration	Content focus & pedagogical goals	Integration of science education	Supervisory models & partnerships	Assessment & reflection	Innovation & policy orientation
Germany	Distributed practicum phases across Länder	Emphasis on interdisciplinary *Sachunterricht*	Moderate to strong science integration, depending on specialization	Mentor models vary by state	Reflections and examinations	Strong curricular support; regional variation
Greece	Practicum mainly in the final years; limited weeks	General pedagogy dominates	Science integration is uneven; mentor-dependent	Mentor preparation limited	Reflective portfolios in some universities	Recent initiatives to strengthen the science focus
Hungary	Expanded practicum duration	Focus on pedagogy and content	Science is often traditional; limited inquiry	Mentor training uneven	Formal assessment with limited reflection	Structural reforms ongoing
Ireland	The extended practicum is integrated throughout	Child-centered pedagogy focuses	The curriculum requires science integration	Strong university-school collaboration	Observations and reflection assignments	Emphasis on IBSE and STEM policy alignment
Italy	5-year program; practicum across all years	Balanced but often theoretical	Science taught, but pre-service confidence is low	Mentor involvement variable	Structured evaluations and journals	Reforms to strengthen science teaching
Latvia	Practicum expanded post-reform	Curriculum-linked pedagogy	Moderate science integration	Developing mentor training	Reflective reports	Policy alignment with EU competence frameworks
Lithuania	Practicum structured with growing duration	Emphasis on pedagogy	Science integration developing	Mentor support moderate	Assessment varies by institution	Gradual adoption of inquiry-based approaches
Luxembourg	Small system; practicum extended	Curriculum and multilingual pedagogy focus	Science is included in thematic teaching	Close mentor-university collaboration	Reflective and performance-based assessment	Alignment with EU STEM priorities
Malta	Practicum extended; linked to professional practice	Pedagogy focus	Science lessons required during practicum	University tutors are closely involved	Reflection journals	Integration of IBSE through curriculum reform
Netherlands	Dual pathway: university + school	Research-based, inquiry-focused pedagogy	Science integrated through structured assignments	Strong partnerships; mentor training	Systematic feedback and peer reflection	High level of innovation and alignment
Poland	15-20 weeks practicum	Focus on classroom management	Science via environmental studies; limited inquiry	Mentor training moderate	Formal evaluation, limited reflection	Policy alignment is growing, practice lags
Portugal	Practicum extended in master's programs	Integrated pedagogy	Science integration is improving, but resource-limited	Mentor training uneven	Portfolios and reflective tasks	IBSE promoted but unevenly applied
Romania	Extended practicum post-reforms	General pedagogy focus	Science marginal during practicum	Mentor training weak	Assessment formalistic	Infrastructure and mentor capacity challenges
Slovakia	Practicum moderate	Pedagogy-oriented	Limited science teaching opportunities	Developing mentor programs	Assessment basic	Policy aims toward IBSE adoption
Slovenia	Practicum extended; early placements	Balanced pedagogy	Moderate science integration	Structured mentoring	Reflective activities and evaluations	Ongoing innovation in STEM education
Spain	30-40 ECTS practicum	Curriculum-focused	Science integrated through modules; mentor-dependent	Partnerships improving	Portfolio and observation-based assessment	STEM initiatives expanding but uneven
Sweden	Practicum embedded throughout	Inquiry and sustainability focus	Strong integration of inquiry-based science	Institutionalized partnerships	Structured feedback	Innovation through thematic STEM teaching

(1) practicum structure and duration,

(2) content focus and pedagogical objectives,

(3) integration of science education,

(4) supervisory models and partnerships,

(5) assessment and reflection, and

(6) innovation and policy orientation.

This thorough overview facilitates the recognition of cross-national patterns addressed in the subsequent section.

Table 1 delineates the essential characteristics of teaching practicum frameworks in primary science education across all EU member states. Six analytical dimensions are employed for cross-country comparison:

(1) structure and duration of practicums,

(2) content emphasis and pedagogical objectives,

(3) integration of scientific education,

(4) supervisory frameworks and collaborations,

(5) evaluation and reflection, and

(6) innovation and policy orientation.

The information is derived from national teacher education frameworks, Eurydice reports, and contemporary research literature.

CROSS-COUNTRY PATTERNS AND KEY FINDINGS

The comparative analysis among EU member states uncovers various overarching trends and significant discrepancies in the integration of science education within pre-service teachers' practicum experiences. Despite significant structural convergence among national teacher education systems, especially regarding practicum duration, organization, and university-school partnerships, this has not consistently resulted in pedagogical convergence in the integration of science education. The patterns can be categorized into three interconnected domains: structural alignment, pedagogical orientation, and mentor preparation.

A key finding highlights the extensive conformity of practicum structures with European frameworks in the last twenty years. Nearly all EU member states have lengthened practicum experiences, implemented multiple placements at various stages of teacher education, and reinforced formal partnerships between universities and schools (Eurydice, 2022). This convergence illustrates the impact of the Bologna Process and the European Higher Education Area in advancing multi-tiered practicum models that entail progressively greater responsibilities for pre-service teachers (Jakku-Sihvonen & Niemi, 2006).

The degree to which these structural reforms incorporate targeted science education components varies considerably. In numerous countries, practicum continues to be discipline-general, with science education objectives either implicitly integrated or delegated to the judgment of individual schools and mentors. In contrast, in nations like Finland, the Netherlands, and Sweden, science education is explicitly incorporated into practicum learning objectives, providing organized opportunities for inquiry-based instruction and reflection (Juuti & Lavonen, 2016). These disparities underscore that structural alignment is a requisite yet inadequate condition for guaranteeing uniform integration of science education within teacher education systems.

A second significant finding pertains to variations in pedagogical orientation. Educational systems in Central and Northern Europe typically implement research-informed, inquiry-based methodologies for science instruction during practicum, facilitated by reflective seminars and strong partnerships between universities and schools (Jakku-Sihvonen & Niemi, 2006; Jorde & Dillon, 2012). Conversely, in numerous Southern and Eastern European settings, practicum experiences predominantly emphasize general classroom management and literacy, while science is frequently regarded as secondary (García-Carmona & Zubimendi, 2020; Kallery et al., 2009). This educational marginalization exacerbates enduring disparities in pre-service teachers' confidence and proficiency in science instruction, as extensively documented in international studies (Appleton, 2003; Kind, 2009).

IBSE is recognized as an essential pedagogical approach for enhancing students' scientific literacy and engagement (European Commission, 2015; Osborne, 2023). Recently, digital tools and artificial intelligence have started to impact the preparation of science teachers, with research indicating that AI applications like ChatGPT can assist pre-service teachers in creating physics experiment worksheets and improving inquiry-based practicum experiences (Kotsis, 2024). Artificial intelligence is increasingly framed within a pedagogy-technology-policy framework that redefines physics education in STEM classrooms (Kotsis, 2025a), emphasizing the necessity for teacher education programs to incorporate AI literacy, ethical usage, and curriculum integration. Recent research underscores that the proficient incorporation of AI into digital technologies can improve science pedagogy, providing innovative instructional design, experimentation, and tailored feedback for pre-service teachers during practicum experiences (Kotsis, 2025b). Nonetheless, the degree to which pre-service teachers engage in and implement IBSE during their practicum is inconsistent. In environments where science is thoroughly integrated, pre-service teachers are afforded opportunities to design, execute, and evaluate inquiry lessons with systematic mentor feedback. In contexts where science is peripheral, such opportunities frequently consist of isolated lessons or theoretical discussions, with scant implementation in the classroom. These findings emphasize the necessity of explicitly integrating science education objectives into practicum curricula instead of presuming they will develop naturally.

A third essential pattern pertains to the preparation and professionalization of mentors. In all regions, mentor teachers are essential in facilitating the practicum experiences of pre-service teachers, especially in science education (Friedrichsen et al., 2011; Vangrieken et al., 2017). In countries like Finland, the Netherlands, and certain regions of Scandinavia, mentors undergo formal training and frequently maintain connections with universities, allowing them to assist pre-service teachers in PCK and inquiry-based instructional methods (Juuti & Lavonen, 2016).

Conversely, in Southern and Eastern Europe, the processes of mentor selection and training tend to be less structured, with minimal focus on science-specific mentoring. This may lead to variability in practicum experiences based on the individual mentor's background and interest in science. The absence of organized mentor training in science constitutes a major obstacle to the reliable application of inquiry-based science instruction, despite the existence of structural frameworks for practicum.

Collectively, these patterns indicate a tripartite disparity among EU policy frameworks, national structural reforms,

Table 2. Classification of EU member states according to the strength of teaching practicum in science education

Category	Key characteristics	Countries
Strong	Early & extended practicum; inquiry-based science integration; strong mentor training; robust university–school partnerships; structured reflection	Finland, Netherlands, Sweden, Denmark, Estonia, Ireland, Belgium, Germany (selected Länder)
Moderate	Structural reforms in place; uneven science integration; mentor quality varies; growing policy alignment	Austria, France, Spain, Portugal, Italy, Luxembourg, Czech Republic, Latvia, Lithuania, Slovenia, Poland
Weak	Short/late practicum; limited science teaching; weak mentor preparation; traditional methods persist	Greece, Bulgaria, Romania, Hungary, Croatia, Slovakia, Cyprus, Malta

and the actual pedagogical practices in science education during practicum. Structural convergence has established a unified framework throughout Europe; however, disparities in pedagogical orientation and mentor capacity persist, leading to varied opportunities for pre-service teachers to cultivate expertise in science instruction. The nations exhibiting the most substantial integration, such as Finland and the Netherlands, amalgamate extensive practicum frameworks with clear science education goals and exceptionally qualified mentors. Conversely, systems characterized by weaker integration often depend on generalist practicum experiences and haphazard mentoring, resulting in lost opportunities for cultivating inquiry-oriented science teaching competencies.

These findings underscore the necessity of multi-tiered alignment among EU policy, national frameworks, practicum curricula, and mentor training to guarantee that all pre-service teachers in Europe are adequately prepared to teach science proficiently. In the absence of such alignment, structural reforms alone are improbable to yield consistent enhancements in science education outcomes.

Table 2 presents a comparative classification of EU member states according to the robustness of their teaching practicum frameworks in primary science education, synthesizing the patterns identified in the prior analysis. This classification is based on six analytical dimensions:

(1) practicum structure and duration,

(2) content focus and pedagogical objectives,

(3) integration of science education,

(4) supervisory models and partnerships,

(5) assessment and reflection, and

(6) innovation and policy orientation.

The grouping into strong, moderate, and weak categories followed a qualitative decision rule. Countries were classified as strong when they demonstrated consistently high performance across the majority of dimensions, particularly in the explicit integration of science education into practicum, the presence of inquiry-based pedagogies, and the professionalization of mentoring. Countries were classified as moderate when structural frameworks were in place but science integration, mentoring quality, or pedagogical innovation appeared uneven or inconsistent. Countries were classified as weak when practicum experiences were short or late in the program, science education was marginal or optional, and mentor preparation and inquiry-based practices were limited. This typology, therefore, reflects the overall pattern across dimensions rather than performance on a single indicator. The classification underscores both structural convergence within the EU and enduring disparities in the integration of science education, mentor preparation, and pedagogical innovation. This synthetic summary connects the comparative results with the ensuing discourse on policy and teacher education ramifications.

The patterns discussed above can be synthesized into a three-tier classification of countries based on the strength of their teaching practicum in science education. This classification highlights structural and pedagogical disparities across the EU and provides a framework for targeted policy interventions.

CONCLUSION

The teaching practicum is a vital stage in the professional development of pre-service primary teachers, especially concerning the enhancement of PCK and inquiry-based instructional skills in science education. This comparative analysis of the 27 EU member states reveals that, although structural convergence has been attained in various facets of practicum organization, including duration, sequencing, and institutional partnerships, the pedagogical integration of science education is inconsistent across national contexts. This disparity highlights the shortcomings of policy-driven structural reforms in the absence of focused pedagogical strategies and professionalization of mentors.

The analysis revealed three interconnected domains with notable disparities:

(1) structural alignment, where EU-level frameworks have resulted in generally comparable practicum models but differing degrees of emphasis on science,

(2) pedagogical orientation, where certain systems emphasize IBSE while others diminish the role of science in generalist practicum experiences, and

(3) mentor preparation, where variations in training and specialization considerably influence the quality and uniformity of pre-service teachers' science teaching opportunities.

Systems in Finland and the Netherlands exemplify how the integration of these three domains can produce strong science education results, while others reveal the repercussions of incomplete or inconsistent execution.

The findings highlight the necessity for multi-tiered coordination among European frameworks, national teacher education policies, university curricula, and school-level practices. Merely prolonging practicum duration or formalizing partnerships is inadequate to guarantee substantive science education experiences. Explicit scientific education objectives should be integrated into practicum curricula, bolstered by structured inquiry-based pedagogies and mentor training initiatives. This corresponds with overarching European objectives of promoting scientific literacy and equipping youth for engagement in knowledge-driven societies.

Future research should concentrate on longitudinal studies that investigate the impact of various practicum models on the evolution of science teaching competencies over time. Further investigation is required regarding the function of mentors as facilitators of inquiry-based science pedagogy, as well as the ways in which institutional partnerships can foster enduring innovation in practicum design. Comparative studies could examine how contextual factors, including curriculum structure, school culture, and teacher autonomy, interact with practicum models to influence pre-service teachers' experiences.

In summary, attaining superior science education during the teaching practicum necessitates a harmonious alignment among policy, structure, pedagogy, and professional development. The European context provides a distinctive setting for analyzing the interaction between transnational frameworks and national traditions, resulting in varied outcomes. This study enhances the formulation of evidence-based teacher education policies by identifying patterns of convergence and divergence, thereby supporting inquiry-based science instruction for all pre-service teachers throughout the EU.

Funding: The author received no financial support for the research and/or authorship of this article.

Ethics declaration: This study is based exclusively on the analysis of publicly available documents, including national policy frameworks, official regulations, Eurydice reports, and peer-reviewed academic literature. No human participants were involved, and no primary data were collected through surveys, interviews, or experimental procedures. As a result, the research did not require approval from an institutional ethics committee in accordance with standard ethical guidelines for studies relying solely on secondary data sources. All sources have been appropriately cited, and the analysis has been conducted with integrity, transparency, and respect for intellectual property.

AI statement: No generative artificial intelligence (AI) tools were used in the collection, analysis, or interpretation of the data presented in this study. The research is based solely on the systematic examination of publicly available policy documents, official reports, and peer-reviewed academic literature. AI-assisted tools may have been used at a limited level for language editing and proofreading purposes only. Such use did not influence the scientific content, arguments, or conclusions of the article. The author assumes full responsibility for the integrity, accuracy, and originality of the work.

Declaration of interest: The author declares no competing interest.

Data availability: Data generated or analyzed during this study are available from the author on request.

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