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Comparative analysis of science education curricula in Germany, Ireland, and Türkiye

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Abstract

This study comparatively examines the science curricula of Germany, Ireland, and Türkiye within the scope of comparative education. Using document analysis as a qualitative research method, the study analyses the curricula in terms of aims, learning areas, learning outcomes, instructional strategies and assessment approaches. The analytical framework of the study was constructed through an integration of curriculum theory, comparative education perspectives, and a cognitive categorization approach adapted from Haladyna's (1997) work. While Haladyna's (1997) framework was originally developed for test item classification, it is employed in this study exclusively as an interpretive heuristic to categorize the cognitive demands reflected in curriculum outcomes. This adaptation serves as one component of a broader, multidimensional curriculum analysis, rather than a standalone theoretical framework, thereby ensuring a nuanced interpretation of pedagogical directives. Findings indicate that the science curricula of Germany and Ireland are structured around student-centered, inquiry-based and interdisciplinary approaches that support scientific process skills and higher-order thinking. In Türkiye, the curriculum emphasizes scientific literacy within a constructivist framework, while its implementation is shaped by a centralized governance structure and large-scale examination practices designed to ensure system-wide standardization. These differences are associated with curriculum design, educational governance, teacher roles and evaluation systems. The study offers comparative insights into curriculum reform, teacher development and science education policy.

Keywords: science curriculum, comparative education, curriculum evaluation, curriculum reform, educational policy, educational assessment

INTRODUCTION

The significance of quality education in today's information-driven societies continues to grow, with science education emerging as a strategic field closely linked to national development goals. Notably, quality education plays a vital role in the economic, social and scientific advancement of societies, thus contributing to overall improvements in welfare levels (United Nations Educational, Scientific and Cultural Organization [UNESCO], 2020).

In this context, contemporary science education extends beyond the traditional transfer of knowledge; it fundamentally aims to foster critical thinking, problem-solving, and analytical skills by developing a robust scientific literacy (Güngör & Özcan, 2026; Kotsis, 2026). Contemporary science curricula play a central role in fostering scientific literacy, equipping individuals with the ability to interpret natural phenomena, engage in scientific inquiry, and apply scientific reasoning to real-world contexts (Kotsis, 2026). With the growing global interest in science education, updating curricula, improving performance in international exams and

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Contribution to the literature

- This study provides a systematic and multi-dimensional comparison of science curricula in Germany, Ireland, and Türkiye.
- This study examines the content of science education and its structural organization within national education systems.
- By integrating content analysis based on document analysis with a comparative education approach, this study goes beyond outcome data to offer an in-depth understanding of the principles underlying science curriculum development.

refining pedagogical approaches have become key priorities in education policies (Organization for Economic Co-operation and Development [OECD], 2023). Thus, comparative education research is used as a strong reference source in terms of sustaining competition between countries and building education systems as innovative, open-to-transformation structures. International comparative education studies systematically analyze the education systems of different countries from multiple perspectives (Phillips & Schweisfurth, 2014). Currently, many nations participate in international assessment exams to evaluate their education systems and various components within them. Many countries are included in international assessment systems to evaluate the effectiveness of their education systems and components. Moreover, science education programs in various countries can be assessed within this framework. International assessments, such as the trends in international mathematics and science study (TIMSS) and the program for international student assessment (PISA), provide valuable data on the quality of science education (Kubow & Fossum, 2007). As revealed by TIMSS and PISA data, understanding the differences in approaches between countries in science education contributes to the development of more effective and context-sensitive education policies (Kubow & Fossum, 2007).

Comparative analysis of science curricula explains why these programs differ across countries. The key factors influencing this variation include the centralization or decentralization of education systems, emphasis on teacher- or student-centered pedagogical approaches, teaching methods employed and the quality of assessment and evaluation systems (Eckstein & Noah, 1985). In Germany, the education system operates within a decentralized framework, where each state develops and implements its own curriculum. This localized structure fosters a more practice-based, flexible and interdisciplinary approach to science education (Adamson & Morris, 2014).

In Ireland, the teaching process is predominantly student-centered, with research- and discovery-oriented learning methods playing a key role in integrating problem-solving and digital competencies (Karampelas, 2025). Meanwhile, Türkiye implements a standardized science curriculum at the national level as part of its centralized education system (Ministry of National Education [MEB], 2024).

The rationale for selecting Germany, Ireland, and Türkiye is grounded in their distinct educational governance models and their recent performance profiles in international assessments. According to the PISA 2022 results, Ireland is classified among the highly equitable and high-performing education systems, demonstrating a strong capacity to combine academic excellence with social inclusion. Conversely, Türkiye represents a highly centralized system managing a massive, geographically diverse student population. While facing challenges in PISA rankings, Türkiye's recent TIMSS 2023 results (von Davier et al., 2024) indicate significant progress and high performance in early science education. Germany provides a contrasting federal model with a strong historical emphasis on STEM and vocational tracking. Within Germany's decentralized system, where education policies vary across 16 states, the state of Baden-Württemberg was selected as the exemplar. This selection is theoretically justified by the state's leading role in establishing the Kultusministerkonferenz national educational standards and its comprehensive integration of MINT (STEM) initiatives within its regional curriculum. While international assessments like PISA and TIMSS highlight significant performance differences, they provide only limited information, focusing mainly on numerical success data while offering little insight into curriculum content, pedagogical structures, and policy-level effectiveness.

More specifically, the country selection was supported by recent international assessment evidence. In PISA 2022 science, Ireland scored 503, Germany scored 492, and Türkiye scored 476, indicating meaningful differences in average science performance across the selected systems. In TIMSS 2023, the countries also displayed contrasting profiles across grade levels, with Türkiye scoring 570 and Ireland scoring 532 in 4th-grade science (while Germany scored lower than Ireland), and Türkiye scoring 530 and Ireland scoring 525 in 8th-grade science. These assessment patterns were not used to make causal claims about curriculum quality; rather, they were used as contextual indicators to support the selection of systems with differing governance structures, curricular traditions, and science achievement profiles.

The selected countries were treated as analytically contrasting cases rather than statistically sampled cases. Accordingly, their selection was based on differences in educational governance, curriculum organization, and international assessment profiles. No inferential statistical testing was used in the case-selection process.

To strengthen the theoretical positioning of the analysis, Haladyna's (1997) framework was considered alongside other widely used cognitive and curriculum-oriented models. For example, Bloom's revised taxonomy (Anderson & Krathwohl, 2001) provides a broad hierarchy of cognitive processes, whereas SOLO taxonomy emphasizes levels of structural complexity in student understanding (Biggs & Collis, 1982). In comparison, Haladyna's (1997) categories were used in this study not as a comprehensive theory of curriculum, but as a practical coding aid for identifying the cognitive orientation of outcome statements and pedagogical expectations embedded in curriculum documents. For this reason, the framework was applied in combination with Bernstein's (2000) curriculum code theory and comparative curriculum perspectives, rather than as a standalone explanatory model.

In operational terms, curriculum statements were coded by examining whether they predominantly required recall of factual knowledge, conceptual understanding, problem solving, critical thinking, or creative application. This procedure allowed the researchers to identify the relative emphasis placed on cognitive demand within each curriculum while maintaining alignment with broader curricular dimensions such as aims, content organization, pedagogy, and assessment.

To address this limitation, this study aimed to conduct a comparative analysis of science curricula in Germany, Ireland, and Türkiye across five key dimensions. The central research question is as follows: How do the science curricula of Germany, Ireland, and Türkiye differ in terms of their structural, pedagogical and evaluative components within these five dimensions?

The study analyses the science curricula of Germany, Ireland, and Türkiye, focusing on their purposes, learning and sub-learning areas, learning outcomes, instructional strategies and techniques and assessment and evaluation methods. Using a qualitative research design and document analysis, the study employs thematic analysis to compare the curricula of these three countries. The findings of this study are expected to establish a scientific framework for the pedagogical orientations of science curricula, offering valuable insights into educational policies and curriculum reforms. While international student assessments such as PISA and TIMSS provide crucial data on the performance levels of countries in science education, existing comparative studies often prioritize statistical results over fundamental curriculum structures and pedagogical approaches.

A systematic literature search was conducted across Web of Science, Scopus, and ERIC databases spanning the years 2000-2025, using combinations of terms such as 'comparative science curriculum', 'Germany', 'Ireland', and 'Türkiye'. The search revealed that no scientific studies in the academic literature directly compare the science curricula of these three nations as a distinct group. Most existing analyses are either country-specific or broad studies that examine multiple countries together (Buehl & Alexander, 2001; Schleicher, 2018; Tsiouri et al., 2024).

International assessment frameworks such as PISA and TIMSS provided contextual reference points for selecting analytically contrasting curriculum cases. However, the present study does not rely on these assessments as direct measures of curriculum quality, nor does it infer causal relationships between assessment performance and curriculum design.

MATERIAL AND METHOD

Theoretical Framework

This study integrates curriculum theory and cognitive taxonomies to establish a multi-dimensional comparative framework. The analysis of the curriculum structures is informed by Bernstein's (2000) theory of curriculum codes, which distinguishes between 'integrated' curricula (emphasizing cross-disciplinary connections and student agency) and 'collection' codes (characterized by strict subject compartmentalization and teacher-directed instruction).

To support the analysis of learning outcomes and pedagogical expectations, Haladyna's (1997) cognitive categories were used as one of the analytical tools in the study. Rather than serving as the sole theoretical basis of the research, the framework functioned as a practical coding aid for identifying levels of cognitive demand reflected in curriculum statements. This use was complemented by broader perspectives from curriculum theory, comparative education, and Bernstein's (2000) curriculum code framework.

Accordingly, the framework was not used to classify curricula hierarchically as "stronger" or "weaker," but to identify differences in the relative emphasis placed on recall, understanding, problem solving, critical thinking, and creative application.

Research Model

This study builds upon the author's doctoral research (Yalkın, 2024). This study is based on a systematic and in-depth comparison of science curricula in Germany, Ireland, and Türkiye. Document analysis, one of the

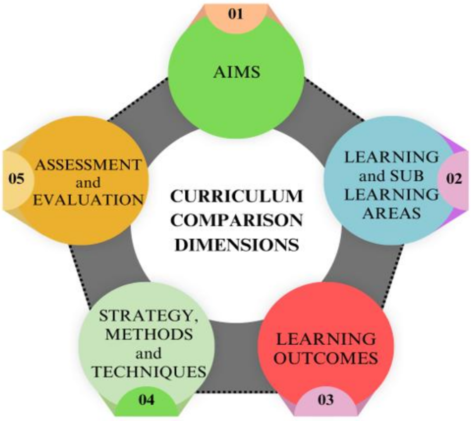

Figure 1. Comparative framework for analyzing science curricula across five key dimensions (the authors' own elaboration)

qualitative research designs, was used, which is a method widely used in the literature of educational sciences that allows for detailed and systematic examination of written materials such as educational policies and curricula (Bowen, 2009; Wach et al., 2013).

The analytical dimension of this study focuses on evaluating the science curricula of Germany, Ireland, and Türkiye across five key dimensions. These dimensions were established based on the research questions and were informed in part by Haladyna's (1997) cognitive categories. However, the analytical model was not limited to that framework alone. Instead, the study combined cognitive categorization with curriculum theory and comparative education principles in order to examine the curricula across five interrelated dimensions. In this sense, Haladyna's (1997) categories served as an auxiliary coding resource for identifying cognitive demand, while the broader comparative framework guided interpretation of curriculum structure, pedagogy, and assessment.

Throughout the research process, the cognitive levels of learning outcomes in the curricula, the pedagogical orientations of teaching methods and the fundamental characteristics of assessment and evaluation systems were examined in detail. In addition, to offer a clearer and more comparable perspective on the structure of international science education practices, the findings were summarized with structural and thematic coherence and visually represented in **Figure 1**. This model serves as a foundational framework for understanding the similarities and differences among the three countries.

Data Sources

The science curricula analyzed in this study were sourced from the official websites of the respective countries' educational institutions. In Türkiye, the science course curriculum was obtained from the MEB (2024). In Germany, the Biologie, Naturphänomene und Technik (BNT) and Naturwissenschaft und Technik (NwT) curricula from the Baden-Württemberg state gymnasium school type (Ministerium für Kultus, Jugend und Sport Baden-Württemberg, 2016a, 2016b) were examined. In Ireland, the junior cycle science course curriculum, developed by the National Council for Curriculum and Assessment (2015), was reviewed. Further details are provided in **Table 1**.

These programs were selected to provide a representative sample of the educational systems in the countries examined. Given the state-specific variations in Germany's highly decentralized federal education system, the curriculum from the State of Baden-Württemberg was selected based on methodological constraints and direct field research opportunities. The researchers conducted official field visits to Stuttgart, Baden-Württemberg, and Paderborn, North Rhine-Westphalia within the scope of the Erasmus+ project "STEM in action". These visits provided direct interaction with educational attachés and facilitated reliable access to regional curriculum documents, making Baden-Württemberg the most methodologically sound choice for the German context.

Data Collection Process

The data sources for this study consist of published documents on official curricula and educational policies. During the data collection process, the original languages of the curricula (Turkish, German, and English) were considered; the texts were initially translated into Turkish by the researcher and subsequently verified by field experts. The researchers conducted official field visits to Stuttgart, Baden-Württemberg, and Paderborn, North Rhine-Westphalia within the scope of the Erasmus+ project "STEM in action", which provided direct interaction with educational attachés and access to reliable regional curriculum documents, making Baden-Württemberg the most methodologically sound choice for the German context. German sources were reviewed by teachers affiliated with the foreign branch of the Ministry of National Education in the State of Baden-Württemberg, while the accuracy of English sources was verified by English teachers associated with the Ministry of National Education in the State of Baden-Württemberg.

Table 1. Curricula used in the study

Country	Source curriculum	Publication year	Education management
Türkiye	Science curriculum	2024	Centralized, MEB
Germany	BNT and NwT course schedules (State of Baden-Württemberg)	2016	Federal (state based)
Ireland	Junior cycle science curriculum 2015	2015	Center (flexible delivery)

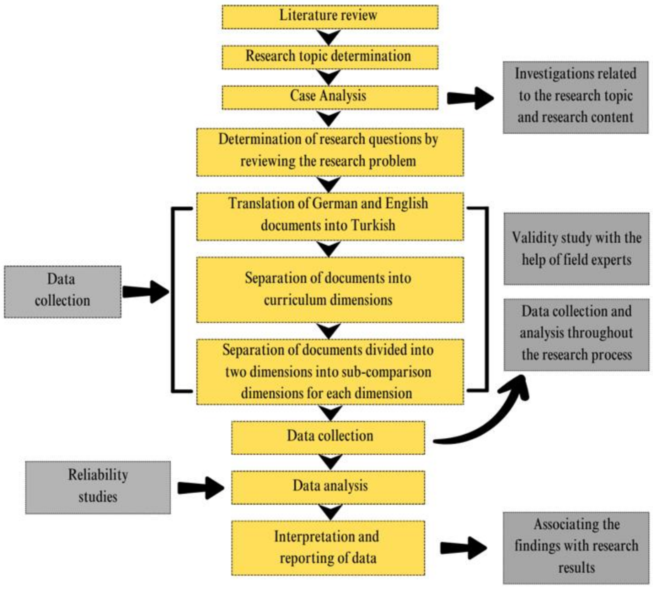

Figure 2. Research process and design framework (the authors' own elaboration)

To reduce cross-linguistic interpretation bias, the translation process involved three stages: initial translation by the researcher, expert review by bilingual subject specialists, and comparison of translated segments against the original curriculum statements during coding. Rather than treating translation as a purely technical step, the study approached translation as part of the interpretive process, and potentially ambiguous pedagogical terms were reviewed collaboratively before final coding decisions were made.

Data Analysis

The research process was conducted systematically and in sequential stages. First, the research topic was identified through a literature review, and the science curricula to be analyzed were selected. During this phase, German and English documents were translated into Turkish. The translated documents were then categorized according to the fundamental dimensions of the curriculum, the data were further sub-divided based on predefined categories and comparative analyses were conducted. The data obtained were analyzed using MAXQDA 24, a qualitative data analysis software, to facilitate the interpretation and reporting of findings. In addition, to ensure reliability and validity, expert opinions were sought and collaboration with specialists was maintained throughout the data collection and analysis process. In the final stage, the findings were interpreted in relation to existing literature. A detailed diagram illustrating the research process is shown in **Figure 2**.

The timeline of the study encompasses a series of procedures, including document collection, translation, coding, categorization and interpretation of findings. The research process was completed in the 2023-2024 academic year. Initially, the documents were translated, followed by coding and categorization processes that were conducted through content analysis. The research focuses on the German state of Baden-Württemberg, Ireland's national education system and Türkiye's secondary school science education programs established by the Ministry of National Education. The analyzed documents were published by the official institutions responsible for shaping education policies in these countries. These documents were used as the main data source for the comparative evaluation.

This study was performed without any intervention, considering the contents of the current curriculum. To ensure the data's validity and reliability, the documents examined were obtained directly from official sources; interpretations were made in light of the current academic literature in the field. The primary goal of this study was to contribute to the findings by offering academic and constructive recommendations for the development of science curricula. The researcher employed content analysis and thematic analysis methods to examine the curriculum (Krippendorff, 2018).

The unit of analysis for this study was strictly defined as the individual learning outcome statements and pedagogical directives within the official curriculum documents. A comprehensive codebook was inductively and deductively developed, detailing main themes, sub-themes, and explicit coding rules. This codebook is provided in **Appendix A** to ensure full methodological transparency and reproducibility.

The comparative analysis of the curricula was structured using Haladyna's (1997) taxonomy of cognitive skills and conducted in alignment with five key analytical pillars, namely, purposes, hierarchical learning structures, expected outcomes, instructional methodologies and evaluation models. The coding process was performed in three main stages according to the thematic analysis approach suggested by Strauss and Corbin (1990). During the initial stage of the coding process, open coding was employed to examine science curricula in detail, focusing on their learning outcomes and pedagogical structures. The data obtained from this examination were collected under meaningful code categories. During the axial coding stage, conceptual connections and structural relationships within the data were analyzed, leading to the identification of prominent code patterns. In the final stage, selective coding, the identified themes were interpreted based on similarities and differences between countries, evaluated within a comprehensive framework and examined through a comparative analysis.

Quantitative expressions of curriculum distribution (e.g., 15%, 50%, and 60%) were analytically derived from the proportional presence of specific themes in learning outcomes, instructional guidance, and where available, recommended instructional emphases within the official

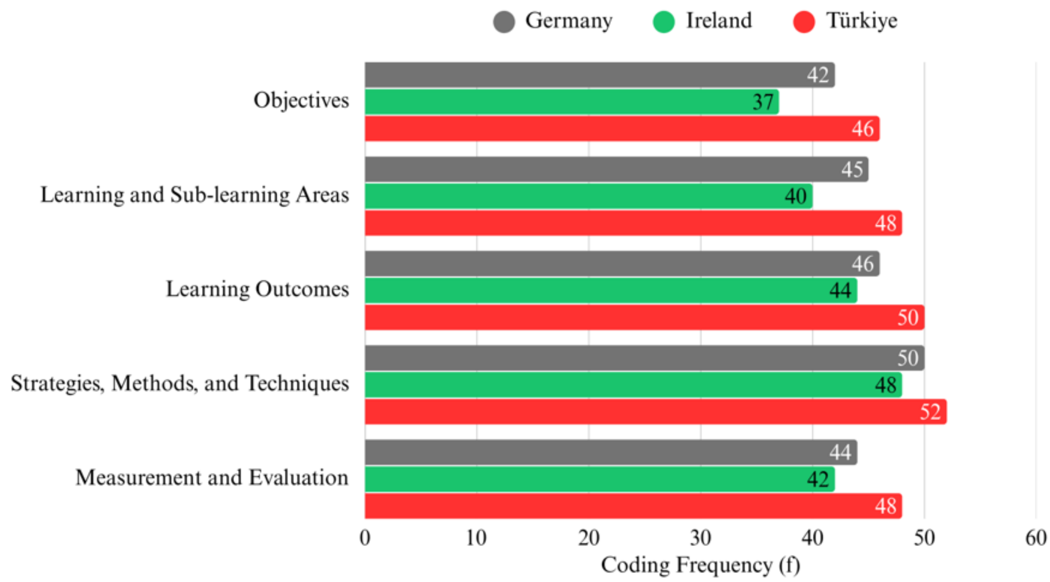

Figure 3. Distribution of coding frequencies across curriculum components in Germany, Ireland, and Türkiye (the authors' own elaboration)

curriculum documents. These percentages should therefore be interpreted as analytical estimates of curricular emphasis rather than as exact instructional time allocations uniformly applied across all schools.

Reliability Studies

To mitigate cross-linguistic translation bias, documents originally in German and English were translated by the researcher and reviewed by bilingual educational experts. Translation accuracy was further checked by comparing coded segments with the original curriculum statements during analysis.

Inter-rater reliability was initially assessed using the Miles and Huberman formula, yielding a 92.46% agreement rate (1,336 out of 1,445 codes). Although percentage agreement was calculated for this initial coding stage, a retrospective Cohen's kappa coefficient could not be computed for all iterative rounds of recoding because the final coding structure and the remaining 109 codes were established through negotiated consensus. Accordingly, percentage agreement is reported for the initial coding stage, while the absence of a kappa estimate for the subsequent consensus-based rounds is recognized as a methodological limitation.

Triangulation example regarding thematic coding process

An example of triangulation in the theme-determination process was observed in the 'curriculum goals' sub-dimension, where three researchers independently labelled the same content using different concepts. The expressions used in this process-'curriculum goal structure', 'instructional intent' and 'purpose of the curriculum'-have the same or common meanings in content, but they differ in terminology.

Due to collaborative evaluation and discussion, these expressions were consolidated under the theme 'objective orientation of the curriculum'. Due to the common understanding developed among the researchers during the process of determining the themes, the methodological integrity of the study was strengthened and an approach compatible with the principles of reliability was demonstrated.

FINDINGS

By focusing on key instructional domains, this study offers a multi-dimensional comparison of the science curricula in Germany, Ireland, and Türkiye, emphasizing how diverse pedagogical ideologies and national education policies influence curriculum content and implementation. The comparative analysis framework adopted in this study is structured as follows. Initially, the general structure of each country's science curriculum is presented. **Figure 3** shows a visual summary of the curriculum structures in the three countries, demonstrating how content areas, pedagogical priorities and assessment criteria are organized within each education system.

Based on the analyses conducted, the systemic foundations of the examined curricula are comparatively summarized in **Table 2**, which synthesizes key differences in educational governance, pedagogical orientation, student participation and assessment strategies in Germany, Ireland, and Türkiye. These parameters reflect each country's underlying curriculum philosophy and implementation logic.

Table 2. Systemic foundations of science curricula

Country	Educational governance	Pedagogical orientation	Student participation	Assessment strategy
Germany	Federal (state-based authority)	Inquiry-based, practice-oriented, interdisciplinary	High (project-based, localized participation)	Performance-based, portfolio and exams
Ireland	Centralized but locally flexible	Student-centered, inquiry-driven, STEM integration	Moderate to high (active, inquiry-oriented participation)	Continuous, project and portfolio-based
Türkiye	Centralized (MEB)	Constructivist within a structured national framework	Moderate within a centrally coordinated model	Nationally standardized exams with summative emphasis

Table 3. Curricular structures and policy alignment

Country	Curriculum model	Policy alignment	Teaching method	Assessment emphasis
Germany	Flexible, regionalized curricula tailored to state policies	Aligned with innovation, federal autonomy and skills development	Hands-on experimentation, cross-disciplinary integration	Competency and performance evaluation
Ireland	Standardized national model with flexible classroom implementation	Aligned with student agency, critical thinking and research skills	Inquiry-based learning, interdisciplinary projects and data-driven investigation	Continuous, classroom-based and inquiry-oriented assessment
Türkiye	Standardized national model focused on curricular coherence	Aligned with national benchmarks, standardized testing goals and system-wide comparability	Structured instruction with emphasis on conceptual development and core scientific content	Outcome-focused summative assessment within nationally coordinated structures

To facilitate an in-depth comparative reading, **Table 3** summarizes the general structure of each curriculum, illustrating how teaching models and assessment mechanisms align with broader policy priorities. For example, **Table 3** contrasts Türkiye's centralized, exam-focused model with the performance-based, student-centered approaches in Germany and Ireland. This visual synthesis provides an analytical framework for the sections that follow.

Table 3 highlights the structural differences among the science curricula of Germany, Ireland, and Türkiye, focusing on management structure, pedagogical approaches, student participation and assessment methods. Germany's state-based education system supports a structure that provides flexibility in teaching processes. Within this structure, problem-based learning (PBL) and performance-based assessment practices are at the forefront. In Ireland, central planning is combined with flexible instructional delivery, supported by an inquiry-based teaching approach and continuous assessment practices. By contrast, Türkiye's model is organized through a centrally coordinated system in which curricular consistency, standardization, and examination alignment play a prominent role. The distinct practices observed across the three countries underscore how curriculum design is closely influenced by each nation's educational strategies, instructional preferences and assessment systems.

Bernstein's (2000) concepts of 'total' and 'integrated' curriculum codes offer a useful framework for interpreting these structural differences. Science programs in Germany and Ireland tend to foster comprehensive learning environments that promote cross-disciplinary movement, emphasize adaptable content and promote active student engagement.

The findings related to the five dimensions in which the curricula were examined are presented below under corresponding headings, within the framework of the comparative analysis.

Objectives of Science Curricula

The science curricula of Germany, Ireland, and Türkiye share a set of fundamental goals, such as developing scientific literacy, improving critical thinking skills and promoting problem-solving abilities. However, the pedagogical approaches and instructional practices employed to achieve these goals vary significantly across the three countries. These differences stem from distinct national educational policies, economic priorities and perspectives on science and technology. The comparative analysis of the curricula reveals the diverse teaching philosophies that underpin these shared goals and underscores the curricular rationales shaping them in each context.

The German science curriculum is characterized by the integration of STEM disciplines, with a strong emphasis on applied learning, laboratory work and PBL. The program was designed to cultivate technology-oriented competencies through the deliberate integration of disciplines such as physics, chemistry and biology with engineering and technology. The content analysis of the German science curriculum revealed 3 overarching themes, 18 sub-themes, and 42 coding frequencies. The most frequently coded themes were STEM-focused education, scientific process skills and

Table 4. Objectives and code frequencies in the science curricula

Country	Main purpose of science education	Learning approach	STEM integration	NMT	NST	CF
Germany	STEM integration, science process skills	Problem-based learning, hands-on training	High	3	18	42
Ireland	Critical thinking, inquiry-based learning	Inquiry-based learning, STEM projects	Medium	2	14	37
Türkiye	Scientific literacy, constructivist learning	Structured knowledge development, centrally coordinated curriculum	Moderate-selective	3	20	46

Note. NMT: Number of main themes; NST: Number of sub-themes; CF: Coding frequency; & "Number of codes" refers to the distinct qualitative categories identified in the analysis, whereas "coding frequency" refers to the total number of times those categories appeared across the analyzed curriculum documents

PBL. Within the STEM-focused framework, themes such as the integration of technology into science instruction, the development of engineering-related competencies and the promotion of interdisciplinary learning environments were emphasized.

The Irish science curriculum emphasizes inquiry-based instruction and the development of critical thinking, placing strong value on interdisciplinary activities and data-driven learning. The curriculum encourages students to engage in scientific exploration by observing phenomena, formulating hypotheses and analyzing information through reflective reasoning. Rather than relying on direct instruction of established methods, the program supports a model where learners actively construct their own understanding through investigation. The content analysis of the curriculum revealed 2 main thematic categories, supported by 14 sub-themes, 34 codes and 37 individual coding entries. The most frequently coded themes were inquiry-based learning and scientific thinking skills. Within the context of IBL, the most prominent sub-themes included student-centered learning, interdisciplinary projects and activities focused on critical thinking.

In Türkiye, the science curriculum prioritizes scientific literacy within a centrally coordinated curricular framework. The program incorporates a constructivist orientation and places emphasis on conceptual understanding, daily-life connections, and the development of problem-solving skills. At the same time, its pedagogical structure reflects the requirements of a national education system designed to maintain coherence, comparability, and common standards across diverse educational settings. The content analysis of the Turkish science curriculum yielded 3 main themes, 20 sub-themes, 42 coding categories, and 46 coding statements. The most frequently coded themes were scientific literacy, structured knowledge building, and central curriculum alignment. Within the overarching theme of scientific literacy, sub-codes such as connection with daily life, comprehension of scientific processes, and interdisciplinary associations emerged as particularly prominent.

The differences in national approaches to science education are largely shaped by pedagogical orientations, science and technology policies and assessment systems. For instance, Germany's education system adopts a STEM-based structure that integrates engineering and technological skills, while Ireland emphasizes learning models grounded in scientific inquiry and critical thinking. Türkiye organizes science education through a centrally structured model intended to support coherence, comparability, and nationwide curricular alignment.

Table 4 presents a comparative overview of the objectives, pedagogical approaches and extent of STEM integration within the science curricula of Germany, Ireland, and Türkiye. In Germany, STEM themes are particularly prominent, with 42 coding frequencies identified during the content analysis. The Irish curriculum emphasizes critical thinking and IBL, supported by 34 distinct codes appearing 37 times. Meanwhile, Türkiye's instructional model focuses on scientific understanding and structured knowledge development, evidenced by 42 codes recorded in 46 instances.

Learning and Sub-Learning Areas

The organization of learning and sub-learning areas within science curricula is shaped by national scientific agendas, instructional strategies and prevailing economic priorities. Comparative evaluation of these curricula reveals notable variations in the implementation of interdisciplinary integration, prioritization of instructional topics and breadth of scientific content coverage. In particular, analysis of the science curricula in Germany, Ireland, and Türkiye emphasizes significant differences in the scope of learning areas, level of disciplinary integration and thematic emphasis embedded in teaching methodologies.

The German science curriculum features an interdisciplinary structure that integrates biology, physics and chemistry with engineering and technology. This approach is designed to support science education in all areas of applied science and technology-focused learning, as well as basic sciences. At the core of the program, students are encouraged to extend scientific concepts beyond theoretical understanding and apply

Table 5. Learning areas and coding frequencies in the science curriculum

Country	Learning areas basic approach	Prominent themes	Learning areas distribution (%)	NMT	NST	NC	CF
Germany	Interdisciplinary integration with STEM	STEM- and engineering-focused education	15	4	16	40	45
Ireland	Emphasis on environmental science and sustainability	Environmental awareness and ecological education	15	3	14	38	40
Türkiye	Foundational science-focused structure	Structured knowledge development, discipline-based organization with interdisciplinary connections	30	4	18	42	48

Note. NMT: Number of main themes; NST: Number of sub-themes; NC: Number of codes; CF: Coding frequency; & "Number of codes" refers to the distinct qualitative categories identified in the analysis, whereas "coding frequency" refers to the total number of times those categories appeared across the analyzed curriculum documents

them within engineering and technological contexts. Aligned with the STEM approach, engineering-based courses constitute 15% of the science curriculum in Germany, with significant emphasis on practical applications in science education. Thus, the content analysis of the learning areas in the German science curriculum identified 4 main themes, 16 sub-themes, 40 codes and 45 coding statements. The most frequently coded themes include interdisciplinary integration with STEM, engineering and applied sciences and experimental and laboratory-based learning. The most frequently coded sub-themes under the theme of interdisciplinary integration with STEM were technology-supported teaching, applied science activities and project-based STEM applications.

Ireland focuses on environmental science and sustainability themes in its science curriculum. In recent years, topics such as climate change, ecosystem protection and sustainable energy sources have been incorporated into the science curriculum, reflecting a growing emphasis on fostering environmental awareness. The Irish science curriculum adopts an integrated model that combines biology, physics and chemistry with environmental science, promoting learning processes that empower students to evaluate environmental change through a scientific lens. In this context, the rate allocated to the environmental sciences learning area was determined as 15%, and it was aimed at encouraging students to actively participate in project-based learning processes on sustainability issues. The content analysis of the Irish science curriculum identified 3 main themes, 14 sub-themes, 38 codes and 40 coding expressions. The most frequently coded themes include environmental sciences and sustainability, interdisciplinary integration and holistic science education. The most frequently coded sub-themes under the overarching theme of environmental sciences and sustainability were climate change education, protection of natural resources and ecological literacy.

The Turkish science curriculum is organized primarily around the foundational science disciplines of biology, physics, and chemistry. Interdisciplinary connections are present, although they are structured differently from the more explicitly STEM-labelled organization observed in Germany. Within this framework, the curriculum places strong emphasis on scientific process skills, conceptual sequencing, and coherence across nationally defined learning areas. Content analysis of the curriculum identified 4 main themes, 18 sub-themes, 42 codes, and 48 coding expressions. The most frequently coded themes were basic science-focused education, structured curriculum coherence, and knowledge organization. The most frequently coded sub-themes included scientific process skills, central curriculum alignment, and theoretical knowledge development.

Table 5 provides a comparative analysis of the learning areas and corresponding instructional approaches within the science curricula of Germany, Ireland, and Türkiye. According to the content evaluation, the German curriculum places significant emphasis on the interdisciplinary connections between science education and subfields such as engineering and applied sciences. Analysis results revealed 40 codes and 45 different coding examples belonging to the German curriculum. In Ireland, interdisciplinary learning is primarily structured around the themes of environmental science and sustainability, emphasizing an integrated approach between ecological and scientific fields. By comparison, Türkiye's curriculum gives greater prominence to the foundational science disciplines, while interdisciplinary links are less explicitly framed through STEM terminology. However, the identification of 42 codes and 48 coding initiatives within the Turkish curriculum suggests ongoing, concrete efforts to incorporate STEM disciplines in a more organized and systematic manner.

Learning Outcomes

The primary aim of science education is to equip students with the skills necessary to engage with scientific knowledge and apply it in meaningful contexts. Although all three countries acknowledge the value of scientific literacy and inquiry-based processes, their teaching methods and curriculum structures are

Table 6. Learning outcomes and code frequencies in science curricula

Country	Learning outcomes basic approach	Prominent themes	Learning outcomes distribution (%)	NMT	NST	NC	CF
Germany	Experiential learning and laboratory-oriented education	Experimental skills, understanding of scientific processes	40	4	14	42	46
Ireland	Education focused on data analysis and critical thinking	Scientific inquiry, data analysis, evidence-based evaluation	65	3	12	40	44
Türkiye	Scientific literacy and problem-solving competence	The relationship between science and daily life, alignment with nationally coordinated assessment structures	25-35	4	16	42	50

Note. NMT: Number of main themes; NST: Number of sub-themes; NC: Number of codes; CF: Coding frequency; & "Number of codes" refers to the distinct qualitative categories identified in the analysis, whereas "coding frequency" refers to the total number of times those categories appeared across the analyzed curriculum documents

shaped by differing national priorities. A comparison of the science curricula in Germany, Ireland, and Türkiye reveals that although a shared emphasis on scientific thinking, analytical skills and problem-solving competencies exists, there are significant differences in how these capabilities are implemented in classroom practice.

The German curriculum focuses on applied learning, particularly through experimental studies and laboratory experiments. The acquisition of experimental skills, an in-depth understanding of scientific processes and the development of critical thinking are fundamental components of science education. This approach, supported by project-based teaching methods, allows students to explore science through real-life experiences.

The Irish curriculum emphasizes the development of data analysis and critical thinking skills. The concepts of scientific literacy, analytical reasoning and interdisciplinary problem-solving guide students in interpreting complex data, examining relationships among variables and drawing evidence-based conclusions. This teaching strategy aimed to develop students' ability to cope with data-intensive and cognitively challenging situations rather than passively transferring knowledge.

In Türkiye, the curriculum emphasizes scientific literacy and problem-solving competencies within a structured instructional framework. The intended learning outcomes encourage students to relate scientific knowledge to daily life and develop conceptual understanding. At the same time, the implementation context of these outcomes appears to be shaped by the broader logic of a centrally coordinated system in which sequencing, alignment, and assessment coherence are given considerable importance. These differing approaches reflect not only variations in curriculum design but also deeper institutional characteristics of the education systems in which they are embedded.

As presented in **Table 6**, the comparative analysis of the science curricula in Germany, Ireland, and Türkiye offers relevant insights into the learning outcomes expected of students within each national context. This study, which was conducted using content analysis and the feature table method, provides a detailed overview of how science education is shaped according to different pedagogical goals and principles.

The German curriculum is distinguished by its emphasis on experiential learning and laboratory-based activities. Within this framework, students are expected to develop skills by engaging directly with scientific processes, formulating hypotheses, using laboratory equipment proficiently and actively participating in experimental design.

In the Irish curriculum, the emphasis shifts to the development of data interpretation and critical thinking skills. The objective is to equip students with the ability to analyze scientific data, construct evidence-based arguments and critically evaluate structured information. These competencies are regarded not only as intended learning outcomes but also as essential elements of contemporary scientific literacy.

In Türkiye, the science curriculum emphasizes the development of scientific literacy and problem-solving competencies within a structured curricular model. Although the curriculum outlines progressive goals, these goals are implemented through nationally coordinated teaching and assessment arrangements. A comparison of how scientific learning outcomes are structured across countries reveals distinct patterns: Germany prioritizes the development of laboratory-based competencies, Ireland emphasizes interpretive reasoning skills, and Türkiye organizes its goals around scientific literacy, conceptual understanding, and system-wide curricular coherence.

Strategies, Methods, and Techniques in Science Curricula

The strategies, methods and techniques employed in science education play a crucial role in fostering students' conceptual understanding and the development of scientific process skills. A comparison of

Table 7. Comparative analysis of teaching methods and strategies in the science curricula of Germany, Ireland, and Türkiye

Country	Teaching process basic approach	Prominent themes	Teaching model distribution (%)	NMT	NST	NC	CF
Germany	Problem-based and laboratory-based education	Experiential learning, engineering-based science education	60	4	18	45	50
Ireland	Inquiry-based and research-oriented education	Scientific hypothesis development, data analysis, independent research	55	3	16	42	48
Türkiye	Constructivist and structured teacher-guided education	Structured knowledge building, teacher-mediated learning	50	4	20	44	52

Note. NMT: Number of main themes; NST: Number of sub-themes; NC: Number of codes; CF: Coding frequency; & "Number of codes" refers to the distinct qualitative categories identified in the analysis, whereas "coding frequency" refers to the total number of times those categories appeared across the analyzed curriculum documents

the science curricula in Germany, Ireland, and Türkiye reveals notable differences, especially in terms of the teaching approaches adopted. These variations reflect each country's educational priorities and preferences for student- or teacher-centered instructional models.

In Germany, experiential learning strategies have long been used as the basis of science education. PBL and laboratory-based activities are among the most frequently employed strategies to enhance student engagement and strengthen problem-solving competencies. Designed to provide hands-on experiences, the German science curriculum places students directly in laboratory environments, enabling them to examine scientific phenomena through experiments. The program is designed to promote active student participation through engineering-focused challenges and develop competencies in designing scientific investigations, analyzing data and conducting independent experimental tasks.

A significant portion of the curriculum-approximately 60%-is devoted to practical laboratory work and experience-based teaching methods. The content analysis of Germany's science curriculum identified 4 main themes, 18 sub-themes, 45 codes and 50 coding examples. The most frequently encountered codes included PBL, laboratory-based applications and engineering-focused science education. In this context, elements such as solving real-world problems, engaging in design activities and applying interdisciplinary methods were emphasized during the coding process; furthermore, each was identified as a central pillar of the German model.

In Ireland, inquiry-based teaching techniques such as IBL and interdisciplinary projects have been adopted in science education. Students are encouraged to actively engage in scientific processes, formulate their own hypotheses and independently evaluate research studies. In the Irish science curriculum, data analysis, scientific thinking and independent research skills are regarded as core components of instruction. Consequently, 55% of teaching time is allocated to IBL techniques, with students taking an active role in IBL activities during science lessons. Content analysis of the Irish science curriculum identified 3 main themes, 16 sub-themes, 42 codes and 48 coding statements. The highest coding frequency was observed in the themes IBL, followed by data analysis-focused education and independent inquiry processes. Within the theme of IBL, sub-themes of student-centered hypothesis development, evidence-based scientific inquiry and experimental data analysis emerged as particularly significant.

Türkiye adopts a constructivist approach in science education while also assigning a strong organizational role to the teacher in structuring learning. The curriculum includes student-centered elements, but these are implemented within a more guided pedagogical environment than in the other two countries. The Turkish science curriculum allocates 50% of its time to learning processes associated with the constructivist teaching model. Content analysis identified 4 main themes, 20 sub-themes, 44 codes, and 52 coding statements. The highest concentration of coding was found within the themes of structured knowledge building, teacher-guided learning, and student-centered constructivist education. Within this thematic pattern, sub-themes such as centrally designed curriculum-focused education, teacher-mediated lesson organization, and selective use of applied learning were particularly prominent.

Table 7 presents a comparative analysis of the strategies, methods and techniques employed in science education programs in Germany, Ireland, and Türkiye. The content analysis reveals the main differences between the approaches adopted by the countries in their teaching processes. Germany adopts a teaching model that promotes active student participation in experimental processes by emphasizing PBL and laboratory-based instruction. The learning process integrates real-life problems and highlights the applied teaching of scientific processes through engineering-oriented science education. In contrast, Ireland employs an IBL approach that centers on the development of scientific hypotheses and data analysis as core elements of the instructional process.

Students are encouraged to independently investigate scientific processes and analyze experimental data through IBL approaches. Although Türkiye has adopted the constructivist education model, the teaching process is organized within a more structured and guided instructional framework. Student-centered approaches are incorporated, but practical activities and inquiry-based teaching methods are embedded within a centrally coordinated pedagogical model. This pattern indicates that inquiry-oriented and student-centered practices are implemented within a more structured instructional environment.

Measurement and Evaluation Approaches in Science Curricula

As a core component of the science curriculum, measurement and evaluation processes are designed to monitor students' academic development, assess the effectiveness of instructional practices and systematically analyze learning outcomes. A comparative examination of the science curricula in Germany, Ireland, and Türkiye reveals striking differences in their approaches to measurement and evaluation. These variations are shaped by each country's national education policies, their preferred methods for assessing student success and the pedagogical frameworks that underpin their learning models.

Germany adopts a process-oriented and performance-based assessment approach that continuously monitors students' learning processes with multi-faceted assessment tools. This approach incorporates various methods, such as student projects, laboratory work, scientific report writing and portfolio-based assessment, to provide students with practical opportunities to develop scientific skills through experiential learning. Content analysis of Germany's science curriculum identified 3 main themes, 14 sub-themes, 40 codes and 44 coding statements. The most frequently observed themes were process-oriented assessment, multiple assessment methods and performance-based assessment. Within the overarching theme of process-oriented assessment, the sub-themes of monitoring individual student development, portfolio assessment and assessment through student projects were particularly prominent.

Ireland uses a holistic and continuous assessment approach that integrates inquiry-based assessment strategies. The Irish science curriculum emphasizes continuous assessment of academic work throughout the year, rather than relying solely on end-of-term examinations. Students are evaluated through laboratory investigations, data analysis and project-based assessments. Furthermore, ~50% of the assessment framework is devoted to continuous and inquiry-based assessment. Content analysis of Ireland's science curriculum revealed 3 overarching themes, 12 sub-themes, 38 codes and 42 coding statements. The most prominent themes were continuous assessment, inquiry-based assessment and performance-based assessment. Key sub-themes within continuous assessment included monitoring student progress throughout the learning process, assessment based on laboratory and experimental activities and evaluation of scientific literacy.

Türkiye's science curriculum is primarily shaped by a centralized examination system, where national assessments such as the high school entrance exam (LGS) and the university placement exam (YKS) function as key instruments for evaluating student performance in science. This structure shapes classroom priorities by encouraging alignment between instruction, curriculum objectives, and nationally standardized evaluation criteria. Approximately half of the overall assessment process comprises centralized exams. The content analysis revealed that Türkiye's curriculum is organized around 3 core themes, supported by 15 sub-themes, 42 codes, and a total of 48 coding instances. Most frequently, references appeared under themes related to centralized test-based assessment, followed by standardized tests aimed at curricular attainment and exams designed to measure individual performance. Noteworthy sub-themes included national testing systems such as LGS and YKS, content-focused test designs, and assessment formats intended to ensure comparability across learners (**Table 8**).

This study examines how assessment processes are addressed within the science curricula of Germany, Ireland, and Türkiye and offers a detailed account of the diverse methods employed as well as the extent to which they are implemented in practice. While evaluation methods that focus on process and measure performance are prominent in Germany's practices, research-based continuous assessment formats and tools play a central role in Ireland's approach. These differences extend beyond pedagogical preferences and reflect the broader frameworks, objectives and national priorities embedded in each country's education policies. The resulting picture illustrates how policymakers align assessment systems with established educational goals, integrate them into curricular structures and strike a distinct balance between curriculum design and the strategic intentions underpinning each nation's education agenda. Ultimately, the model adopted by each country demonstrates that it creates a unique balance between the design of the curriculum and national policy goals.

DISCUSSION

This study explores the science curricula of Germany, Ireland, and Türkiye by analyzing them across five key dimensions, namely, underlying aims, learning domains, instructional strategies, assessment practices and curricular outcomes. Through this multi-faceted lens, this study reveals how educational structures and national policies actively shape science teaching across

Table 8. Measurement and evaluation approaches in the science curricula of Germany, Ireland, and Türkiye

Country	Measurement and evaluation basic approach	Prominent themes	Distribution of measurement methods (%)	NMT	NST	NC	CF
Germany	Process-oriented and performance-based assessment	Student projects, laboratory-based assessment, portfolio assessment	50	3	14	40	44
Ireland	Continuous assessment and research-based measurement	Scientific process monitoring, project-based assessment, data analysis	50	3	12	38	42
Türkiye	Central exam-focused assessment	LGS/YKS-based measurement, tests focused on curricular attainment and standardized evaluation	50	3	15	42	48

Note. NMT: Number of main themes; NST: Number of sub-themes; NC: Number of codes; CF: Coding frequency; & "Number of codes" refers to the distinct qualitative categories identified in the analysis, whereas "coding frequency" refers to the total number of times those categories appeared across the analyzed curriculum documents

diverse cultural and socio-political contexts. The findings underscore substantial differences in curriculum design that extend beyond the structuring of science content to encompass the broader methods used for instruction, assessment and policy measure implementation. Notably, curriculum development is not an isolated process; it is intricately linked with each country's prevailing socio-economic conditions and political ideologies. In Germany, for example, a STEM-driven framework governs the curriculum, where interdisciplinary integration is seamlessly combined with hands-on, laboratory-intensive engineering tasks. This approach emphasizes practical application by connecting scientific understanding to real-world problem-solving, encouraging learners to move beyond passive information absorption and actively engage in investigation and innovation.

Meanwhile, Ireland's curriculum is characterized by an inquiry-driven model that encourages students to explore pressing societal issues such as environmental sustainability, critical thinking and ecological awareness. Central to this approach is a commitment to fostering students as creators of knowledge-empowering them to generate insights through research, data analysis and collaborative projects. This educational strategy aligns with contemporary pedagogical theories and the broader educational objectives advocated by the European Union. Overall, the discussion reveals that the distinct curricular designs in these countries are profoundly influenced by broader socio-economic realities and political priorities. Each nation's approach reflects a unique balance between curriculum innovation and policy-driven intent, demonstrating that effective curriculum planning is as much about responding to national conditions as it is about meeting educational goals.

In Türkiye, the relationship between curriculum design and pedagogical practice appears to be shaped by the interaction between constructivist curricular intentions and the operational demands of a centralized assessment structure (Özünlü, 2025; Taşdelen & Hacıoğlu, 2025). Rather than interpreting this pattern simply as inconsistency, it may be better understood as a systemic balancing process between reform-oriented pedagogical discourse and the administrative need for standardization, comparability, and nationwide coherence. Additionally, while international studies compare science curricula, many of these analyses focus primarily on surface-level content differences. This study contributes by systematically examining multiple dimensions-including pedagogical strategies, assessment systems, and learning outcomes-through a coded analytical approach.

Theoretically, this study contributes to an in-depth understanding of the way curriculum functions as a tool of policy and ideology. By situating pedagogical choices within broader cultural, economic and political structures, this study creates a bridge between curriculum studies and related disciplines such as educational policy analysis and the sociology of education. Therefore, this study provides a conceptual model that can shed light on future international investigations in curriculum research.

A key finding of this study is the impact of assessment systems on pedagogical practice. In Germany, assessment processes are predominantly process-based and performance-oriented, supported by practices such as laboratory work, project-based evaluations and student portfolios. Similarly, Ireland employs continuous assessment models that emphasize research, data analysis and evidence-based learning. Both approaches contribute to the development of scientific process skills and encourage active student participation.

In Türkiye, the education system is characterized by centralized and standardized examinations (e.g. LGS and YKS), which significantly influence assessment processes and teaching practices. Alignment between curriculum and assessment structures plays a defining role in shaping instructional priorities and classroom practices. Consequently, the relationship between pedagogical goals and assessment tools should be understood as part of a broader systemic configuration that affects the implementation of reform-oriented practices.

The study reveals the impact of national policy orientations on curriculum design and implementation. Germany's emphasis on applied STEM education is consistent with broad economic goals for high-tech industries and innovation. Ireland's approach to integrating sustainability and interdisciplinary learning reflects efforts to align with EU directives on environmental education. Türkiye's curriculum design and classroom practices reflect the influence of a centralized governance structure and a nationally coordinated assessment system.

The findings suggest that curricula should be examined not only as pedagogical frameworks but also as instruments of political strategy. The alignment-or lack thereof-between curricular goals and national policy objectives plays a pivotal role in shaping the effectiveness of educational reform efforts and the development of scientific literacy among students. These findings should therefore be interpreted primarily at the level of intended curriculum design and policy structure.

CONCLUSION

This comparative investigation examines how the science curricula of Germany, Ireland, and Türkiye are structured across five key dimensions-purposes, content areas, instructional strategies, student competencies and assessment practices-highlighting key similarities and fundamental differences in educational design. Despite the shared commitment of all three countries to fostering scientific literacy aligned with the demands of the 21st century, the strategies they employ to achieve this goal differ significantly.

Evidently, the foundations of the shared vision are built on divergent educational ideologies, distinct practice models and varying degrees of pedagogical coherence. In Germany and Ireland, science education is structured around interdisciplinary learning, inquiry-driven instruction and active student engagement. These frameworks are influenced by broader international trends that prioritize data literacy, critical thinking and competencies aligned with STEM disciplines. For example, Germany actively encourages student engagement in engineering design processes and applied research, while Ireland focuses on cultivating inquiry and analytical thinking through data-driven tasks.

In Türkiye, the curriculum reflects a constructivist orientation within a centrally coordinated educational structure. Classroom implementation and assessment practices are shaped by national standardization requirements, which influence how curricular goals are translated into practice. This pattern suggests that the relationship between curriculum aims and implementation should be interpreted in light of broader systemic conditions rather than as a simple pedagogical shortcoming.

Furthermore, the competencies that students develop are deeply influenced by these curricular differences. In Germany and Ireland, science curricula are instrumental in cultivating skills, such as experimental reasoning, data interpretation and logical evaluation, by engaging students with authentic, real-world challenges.

Assessment practices further reflect these fundamental differences in educational objectives. Germany and Ireland adopt models that place stronger emphasis on continuous and performance-based assessment, whereas Türkiye relies more heavily on nationally standardized examination structures. These differences demonstrate how assessment systems are closely tied to broader governance arrangements and policy priorities.

These findings suggest that future curriculum reform discussions should consider assessment practices, teacher autonomy, and teaching environments together rather than in isolation. In this respect, the study offers a conceptual foundation for re-examining how scientific knowledge is organized, evaluated, and interpreted within different national curriculum systems.

When interpreting the science curricula of the three countries, it is important to consider their distinct socio-political and structural contexts rather than viewing their differences hierarchically. Each curriculum reflects a particular balance between pedagogical aims, governance arrangements, and national priorities. From this perspective, the observed differences should be understood as alternative policy configurations rather than as simple indicators of curricular superiority or deficiency.

It is also important to distinguish between the intended curriculum analyzed in this study and its actual classroom implementation. Official curriculum documents provide formal pedagogical frameworks, but classroom enactment may vary according to teacher expertise, school resources, local conditions, and assessment structures. For this reason, the present findings should be interpreted primarily at the level of curriculum design rather than direct classroom practice.

In conclusion, this comparative study contributes to international discussions on science education by showing how educational policies, pedagogical approaches, and assessment systems shape curriculum design and students' learning opportunities. The study suggests that science curricula which balance inquiry, flexibility, equity, and contextual coherence may be better positioned to respond to the scientific, environmental, and technological challenges of the 21st century.

Limitations of the Study

This study is subject to several limitations that should be considered when interpreting the findings. First, the research relies exclusively on document analysis of intended curricula; thus, it does not include empirical classroom validation of the enacted curriculum. Second, although inter-coder reliability procedures and expert review were applied, qualitative content analysis inevitably involves a degree of interpretive judgement. Third, the translation of curriculum documents across three distinct languages (German, English, and Turkish) may have introduced minor cross-linguistic interpretation challenges despite verification procedures. Fourth, selecting the state of Baden-Württemberg as a representative case limits the generalizability of the findings to Germany's broader decentralized federal education system. Finally, while international assessment results informed the rationale for case selection, this study does not empirically test causal relationships between curriculum structure and student performance. Future empirical studies employing mixed-methods designs could build upon these findings to explore how these intended curricula are actualized in classroom settings.

Recommendations

Based on the findings of this study, the following recommendations are proposed to enhance the effectiveness and modernity of the science curriculum.

Recommendations for researchers

- Qualitative studies based on teacher and student experiences are required to understand the in-class reflections of the science curriculum. In-depth studies examining the practical applications of the curriculum will increase the applicability of reform proposals.
- Experimental studies should be conducted to evaluate the effects of STEM-based applications in the Turkish context. Such studies will provide empirical evidence on the impact of engineering, technology and science process skills on student achievement.
- Research on the measurement and evaluation dimension of science education should be expanded. The effects of process-based and alternative assessment tools on learning outcomes should be examined in comparison with the central examination system.
- Multi-dimensional curriculum comparisons with different country groups should be emphasized. The development of comprehensive evaluation models compatible with local and universal trends can be facilitated with this approach.

General recommendations based on research findings

- It is recommended that science education in Türkiye further strengthen applied, interdisciplinary, and STEM-oriented components within its existing curriculum framework. The curriculum could incorporate more problem-based, project-based, and experimental practices that actively engage students in the learning process.
- In addition, contemporary themes such as environmental awareness, sustainability, digital literacy and artificial intelligence should be integrated into the science curriculum. This approach will help cultivate students who are not only grounded in the fundamental sciences but also attuned to the pressing challenges of the modern world.
- It is recommended to expand the use of alternative assessment methods that monitor individual development - such as portfolios, projects, observation forms, and report analyses - and to gradually introduce complementary and more flexible assessment practices alongside the centralized examination framework.
- It is essential to update the curriculum at regular intervals and to incorporate feedback from practicing teachers throughout the process.

Recommendations for policy makers and stakeholders

- Despite Türkiye's centralized approach to education management, it is recommended that the science curriculum incorporate flexible components that are responsive to regional needs and diverse student profiles. This approach is likely to increase the quality of teaching at the application level.
- It is recommended that continuous professional development programs be structured to increase teachers' pedagogical competence in science education, with particular emphasis on expanding in-service training focused on applied and student-centered instructional techniques.

Contributions of the Study

This study contributes to comparative science education research by offering a multi-dimensional analysis of science curricula in Germany, Ireland, and Türkiye. By examining aims, learning areas, learning outcomes, teaching strategies, and assessment practices together, the study extends beyond performance-based comparisons and highlights how curriculum design reflects broader governance structures and policy priorities. Additionally, the study contributes methodologically by demonstrating how qualitative document analysis combined with structured coding can be used to compare curriculum systems across different governance contexts.

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APPENDIX A: CODEBOOK AND ANALYTICAL FRAMEWORK

Appendix A presents the analytical codebook developed for the qualitative document analysis of the science education curricula of Germany, Ireland, and Türkiye. The coding process was conducted in MAXQDA 24 and organized around the five main analytical dimensions of the study: objectives, learning areas, learning outcomes, teaching–learning processes, and measurement and evaluation.

It should be noted that the numerical values reported in the manuscript for inter-rater reliability refer to the preliminary coding phase of the broader analytical process. In that stage, 1,445 code applications were compared between coders, and 1,336 of these were found to be in agreement, resulting in an agreement rate of 92.46% according to the Miles and Huberman formula. The remaining 109 coding decisions were subsequently reviewed, discussed, and resolved through negotiated consensus. Therefore, the figures reported in the manuscript reflect the reliability assessment of the initial coding stage, whereas **Appendix A** summarizes the final analytically refined coding framework used for interpretation and comparison.

Accordingly, **Appendix A** does not reproduce every individual code application generated during preliminary coding. Instead, it presents the final conceptual coding structure, including the main dimensions, categories, operational definitions, analytical indicators, and representative thematic contexts that guided the interpretation of the curriculum documents. In this way, **Appendix A** is intended to enhance methodological transparency while preserving the readability of the manuscript.

Table A1. Codebook

Main dimension	Category/code	Operational definition	Analytical indicators	Representative context/examples
Objectives	Scientific literacy	Statements emphasizing the development of scientifically literate individuals who can understand, evaluate, and use scientific knowledge in personal, social, and civic life.	References to informed citizenship, science in everyday life, responsible decision-making, and functional use of science.	Science in daily life; informed citizenship; responsible participation in society
	Inquiry and critical thinking	Objectives related to questioning, reasoning, evidence use, interpretation, and critical examination of scientific claims or phenomena.	Use of verbs such as question, investigate, interpret, compare, justify, evaluate, and reason.	Asking scientific questions; interpreting findings; evidence-based reasoning
	Socio-scientific awareness	Statements connecting science education with ethical, environmental, social, or global concerns.	References to sustainability, environmental responsibility, social consequences of science, or global challenges.	Climate awareness; sustainability; environmental responsibility
Learning areas	Disciplinary knowledge	Curriculum content structured around core science domains and their internal conceptual organization.	Presence of clearly defined subject domains and discipline-based content clusters.	Physics; chemistry; biology; earth and space science
	Interdisciplinary integration	Content linking science with other disciplines or broader applied contexts, including technology, engineering, mathematics, and everyday life.	Cross-curricular links, integrated themes, STEM references, and practical applications of science.	STEM connections; real-life integration; cross-curricular themes
Learning outcomes	Conceptual understanding	Outcomes aimed at explaining, describing, classifying, interpreting, and relating scientific concepts, events, or systems.	Learning statements focused on comprehension, explanation, classification, and conceptual relationships.	Explaining processes; identifying patterns; describing systems
	Higher-order cognitive skills	Outcomes requiring analysis, evaluation, interpretation, problem-solving, argumentation, or the production of new ideas and models.	Indicators are associated with higher-level thinking, including comparing evidence, evaluating claims, and generating solutions.	Analyzing evidence; evaluating claims; designing solutions
	Scientific process and practical skills	Outcomes related to experimentation, observation, measurement, inquiry procedures, data collection, and scientific communication.	References to practical investigation, observation, measurement, recording, and procedural skills.	Conducting experiments; making observations; using scientific tools

Table A1 (Continued).

Main dimension	Category/code	Operational definition	Analytical indicators	Representative context/examples
Teaching–learning processes	Student-centered approaches	Teaching strategies that position the learner as an active participant in constructing scientific understanding.	Emphasis on inquiry-based, problem-based, collaborative, exploratory, or participatory classroom practices.	Inquiry-based learning; collaborative learning; problem-based learning
	Context-based learning	Approaches emphasizing the application of science to authentic, social, local, or everyday contexts.	Use of real-life problems, local issues, everyday situations, and meaningful contexts to support learning.	Daily life connections; local issues; applied science contexts
	Digital and technological support	Use of digital tools, technological resources, or technology-supported learning practices in science teaching.	References to simulations, digital resources, ICT integration, technology-supported inquiry, and digital literacy.	Simulations; digital literacy; ICT-supported instruction
Measurement and evaluation	Formative assessment	Assessment practices are used to monitor, support, and improve learning during the instructional process.	Ongoing feedback, observation, classroom assessment, self-assessment, and assessment for learning.	Observation; feedback; portfolios; classroom-based assessment
	Summative assessment	Assessment practices are used to evaluate student achievement at the end of a unit, term, or learning cycle.	End-point testing, written exams, standardized evaluations, and outcome-oriented assessment tools.	Written exams; tests; end-of-unit evaluation
	Process-oriented evaluation	Assessment emphasizing learning progression, skill development, and performance over time rather than only final products.	Continuous assessment, developmental monitoring, performance tasks, and process documentation.	Continuous assessment; developmental monitoring; performance tasks

Methodological Note

The coding framework presented in this appendix reflects the final analytical organization of the study. While the preliminary coding phase generated a larger number of individual code applications for reliability comparison, the categories presented here represent the refined thematic structure used in the final comparative interpretation of the curriculum documents. Therefore, this appendix should be read as a representation of the final codebook rather than as a line-by-line listing of all individual coding instances produced during the initial coding stage.

Additional Note on Analytical Use

The categories and sub-categories listed above were used to ensure conceptual consistency across the comparison of Germany, Ireland, and Türkiye. Frequencies reported in the findings section are analytical representations of thematic density within the curriculum documents and are used to support qualitative interpretation rather than to make statistical generalizations.