ICT Tools in National Curricula of Science

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Abstract

This study investigates the representation of information and communication technologies (ICT) in national and regional science curricula, addressing a gap in understanding how digital tools and their pedagogical functions are conceptualized at the policy level. ICT is widely recognized for its potential to support inquiry, visualization, data handling, collaboration and conceptual understanding in science education. A qualitative comparative content analysis was conducted on 21 science curricula from diverse educational systems. Two research questions guided the study: 1) Which types of ICT tools are referenced in national and regional science curricula? and 2) For which pedagogical purposes are these tools positioned or recommended within curricular descriptions? Drawing on established literature highlighting recurring ICT tool categories and pedagogical functions, the study employed a dual typology comprising five ICT tool categories and five pedagogical functions. Each ICT-related reference was coded according to both dimensions. The analysis identified 133 relevant excerpts, with display and investigation technologies being the most frequently referenced tool category. This indicates that curricula commonly associate ICT with forms of scientific exploration. General digital technologies also appeared frequently, often without specific instructional purpose. Regarding pedagogical functions, ICT was most commonly associated with resource access and lesson organization, followed by inquiry and knowledge presentation. Meanwhile, references to assessment, feedback and structured collaboration were comparatively limited. Cross-tabulation showed that many ICT references support general organizational aims rather than discipline-specific scientific practices. The findings suggest that although ICT is widely acknowledged across contemporary science curricula, its pedagogical role is often described in broad or unspecific terms. Thus, clearer curricular guidance may be needed to support integration of ICT into inquiry and conceptual reasoning in science education.

Keywords: *ICT tools, pedagogical functions, inquiry-based learning, science curricula.*

1. Introduction

The integration of information and communication technologies (ICT) into education has reshaped how science is taught. Digital tools enable new forms of inquiry, visualization, and experimentation that promote active engagement and scientific reasoning. ICT allows students to explore complex or abstract phenomena through simulations, data analysis, and modeling, thereby connecting theoretical understanding with empirical practice. This shift reflects broader constructivist and sociocultural views of learning, positioning technology as a medium for both exploration and conceptual change (Webb, 2005; Hennessy et al., 2007). When effectively integrated, technology helps enhance conceptual understanding, metacognition, and collaborative skills (Baggott La Velle et al., 2003).

Moreover, ICT transforms learning environments by enabling authentic inquiry-based experiences through virtual laboratories, interactive models and data collection tools. These affordances make science education accessible to learners regardless of material constraints, fostering inclusivity and deeper cognitive engagement. Digital tools thus redefine science learning as participatory and exploratory, preparing students to interpret and act within a technologically mediated world. However, despite extensive research on ICT in science education, little is known about how national curricula conceptualize ICT tools and their pedagogical functions, a gap that the present study seeks to address.

To understand how these affordances are translated into policy, it is necessary to examine how national curricula conceptualize ICT in science teaching (Savec, 2017; Huang et al., 2021).

2. ICT in Science Teaching

2.1 Pedagogical Affordances of ICT and the Significance of Curriculum

Digital technologies have become increasingly integral to science education, offering possibilities for inquiry, visualization, modeling, data handling, collaboration, and formative assessment that extend beyond the capacity of traditional classroom resources. Research demonstrates that ICT tools can support students in observing scientific phenomena, manipulating variables when carrying out experiments, generating representations, and constructing explanations, thereby enabling forms of cognitive engagement central to scientific literacy. These affordances align with contemporary visions of science education emphasising investigation and reasoning. The educational value of digital technologies thus extends beyond technical enhancement; they can shape how learners encounter, interpret and understand scientific ideas (Webb, 2005; Hennessy et al., 2007; Savec, 2017).

Given this potential, science curricula play a decisive role in framing how ICT enters the classroom. Curriculum documents are considered authoritative statements of educational purpose, shaping both teacher expectations and system-level priorities. When curricula specify particular ICT technologies or highlight some of their pedagogical uses, they influence the extent to which ICT is viewed as essential, optional, organizational, or inquiry-driven. Conversely, when digital tools are described only in general terms, teachers may be left without guidance for integrating ICT meaningfully into scientific learning. Examining how curricula conceptualize ICT is therefore important for understanding national directions in science education, the degree to which digital practices are embedded in official frameworks, and the kinds of scientific activities teachers are encouraged to implement. Curriculum analysis provides insight not only into classroom enactment but also into the intended role of technology at the policy level and the pedagogical expectations associated with its use (Masters et al., 2015; Tsivitanidou et al., 2021).

2.2 Typology and Classification of ICT Tools in Science Education

Research in science education has generated extensive literature on how different forms of digital technology contribute to students' scientific learning. A consistent finding across relevant studies is that ICT tools are best understood not by their technical features alone but by the educational opportunities and scientific practices they enable. Literature describes several recurring categories of digital tools. One category consists of technologies designed to support investigation and scientific modeling, including simulations, virtual laboratories, digital microscopes, interactive particle or molecular models, and probeware systems capable of performing real-time measurements. These tools allow learners to engage in practices that mirror authentic scientific inquiry: controlling variables, observing processes, constructing or testing models and working with data that could be inaccessible in school environments.

A second category comprises information-oriented technologies such as digital textbooks, online reference collections, curated scientific databases, and web-based instructional resources that provide structured access to disciplinary knowledge. These tools act as gateways to scientific information, complementing inquiry by supplying explanatory materials, conceptual frameworks, and authoritative sources. A third category supports communication and connectivity, including learning platforms and collaborative digital environments. Through these platforms, learners can participate in scientific dialogue, exchange data, justify interpretations, and engage in reasoning practices fundamental to science learning. A fourth category concerns data handling technologies, such as spreadsheets, graphing applications, modeling programs, automated data loggers, and statistical tools that allow students to represent, manipulate, and interpret empirical information. Educational literature emphasizes that these tools support the epistemic work of science by enabling pattern recognition, trend analysis, argument construction, and evidence-based reasoning. Finally, a fifth category, often described as general digital technologies, includes non-specific ICT tools or general computing environments that support learning without explicit pedagogical detail. These categories provide a structured way of conceptualising the technological landscape of science classrooms (Hora & Holden, 2013; Hennessy et al., 2007; Gezer & Durdu, 2025; Savec, 2017).

Besides classifying digital tools, the literature describes a complementary set of pedagogical functions that ICT is expected to fulfill in science education. A central function is assessment and feedback, where digital quizzes, automated scoring systems, and analytics dashboards provide real-time information about student understanding. These tools assist teachers in monitoring progress and offer learners opportunities for immediate reflection, correction, and consolidation. A second function is

collaboration and communication, where digital platforms enable students to articulate ideas, co-construct explanations, negotiate meanings, and share data. Such collaborative uses of ICT reflect broader epistemological shifts toward viewing science as a social activity grounded in discourse and collective reasoning. A third function concerns inquiry and experimentation: digital technologies allow learners to design investigations, model natural phenomena, explore scientific systems through controlled manipulation, take measurements, and iteratively refine predictions. These tools enable processes central to scientific practice, particularly in contexts where physical experimentation is constrained. A fourth function is knowledge presentation, where digital animations, visualizations, simulations, and multimedia representations help communicate complex ideas, illustrate invisible processes, or demonstrate conceptual relationships. These representations play an important cognitive role by reducing abstraction and supporting conceptual change. A fifth pedagogical function relates to resource access and lesson organization: digital repositories, learning platforms, and organizational tools allow structuring classroom activities, supply instructional materials, and facilitate the flow of information between teachers and students. This organizational dimension is integral to how ICT shapes the conditions for science learning. Across the literature, these five functions appear consistently as the core ways whereby digital technologies influence scientific learning, teaching processes, and classroom organization (Savec, 2017; Dini et al., 2024).
Taken together, the bodies of research on the types of digital tools used in science education and on the pedagogical functions they serve provide a comprehensive framework for understanding ICT integration in science teaching. They reveal that ICT use in science education cannot be reduced to either tools or activities but instead reflects a set of interconnected technological and pedagogical dimensions. These dimensions emerge across empirical and theoretical studies despite variations in terminology or classification detail. As such, they form a coherent conceptual lens for examining how ICT is incorporated into curriculum documents and how educational systems position digital technologies within the broader aims of science teaching and learning. The insights drawn from the literature therefore establish the foundation for the analytical orientation of the present study, particularly in relation to understanding how curricular references to ICT reflect broader pedagogical intentions and technological possibilities (Hora & Holden, 2013).

3. Methodology

Research in science education has consistently shown that digital technologies support a wide range of scientific practices, from investigation and modeling to collaboration, assessment, and resource organization (Hora & Holden, 2013; Gezer & Durdu, 2025; Savec, 2017; Dini et al., 2024). This raises an important question about how such applications are reflected in national curriculum frameworks, which define the expectations that shape classroom practice. Examining curricula helps to understand how educational systems position ICT within science teaching and to identify the pedagogical purposes attributed to it. This study addresses this need through a qualitative comparative content analysis of contemporary science curricula, analyzing how ICT is described, its assigned functions, and the coherence of its representations across educational systems (Cohen et al., 2017).
Two research questions guided the analysis:
RQ1: Which types of ICT tools are referenced in national and regional science curricula?
RQ2: For which pedagogical purposes are these tools positioned or recommended within curricular descriptions?
These questions reflect the dual focus on the technological and pedagogical dimensions of ICT in the literature. They also helped structure the analytical framework employed in the study. The sample consisted of 21 national and regional science curricula that were publicly accessible in their most recent versions. These included curricula from Greece, Cyprus, France, the United Kingdom, Ireland, Iceland, Sweden, Norway, Finland, Estonia, Poland, the United States (Next Generation Science Standards), Ontario (Canada), India, Singapore, South Korea, Nepal, Australia, New Zealand, and South Africa. The inclusion of diverse educational systems allowed for meaningful comparison and provided a robust basis for exploring patterns in how ICT is conceptualized internationally (Masters et al., 2015).
The design of the coding system was directly informed by the literature review. Research in science education consistently highlights two dimensions that structure ICT use. The first concerns the types of digital tools employed in science learning, including technologies that support investigation through simulations and modeling environments; tools that provide information through digital resources; tools that facilitate communication through collaborative platforms; and tools that enable measurement and analysis through data handling applications. The second concerns the pedagogical functions

associated with these technologies, such as assessment and feedback, collaboration and communication, inquiry and experimentation, knowledge presentation, and resource organization. These themes formed the conceptual basis for developing a dual typology appropriate for the analysis of curriculum documents (Baggott La Velle et al., 2003; Hennessy et al., 2007; Hora & Holden, 2013; Savec, 2017).

Table 1: Codes, Associated Categories and Their Descriptions and Examples

ICT TOOLS (1st Research Question)		
Code	**Category Name**	**Description of Category**
1.1	Display & Investigation Technologies	Tools enabling observation, measurement, modeling, simulation, or investigation of scientific phenomena, including simulations, virtual labs, digital microscopes, interactive models, and visualization tools
1.2	Information Technologies	Tools providing access to digital resources, structured content, and information retrieval systems, including digital textbooks, websites, databases, and information retrieval systems
1.3	Connectivity Technologies	Tools that support communication, collaboration, networking, and shared workspaces, including learning management systems, discussion forums, video conferencing tools, and shared cloud workspaces
1.4	Data Technologies	Tools for data collection, logging, modeling, graphing, and analysis, including data-logging software, spreadsheets, and sensors
1.5	General Digital Technologies	Non-specific references to ICT infrastructure, general digital tools, or unspecified technological resources, including computers, tablets, generic digital devices, or unspecified “ICT tools” or “digital resources”
PEDAGOGICAL FUNCTIONS (2nd Research Question)		
Code	**Category Name**	**Description of Category**
2.1	Assessment & Feedback	Digital tools used for formative assessment, monitoring, feedback, and evaluation processes, including digital quizzes, automated feedback systems, e-assessment platforms, and self-assessment tools
2.2	Collaboration & Communication	Digital platforms and technologies supporting interaction, discussion, and cooperative learning, including online group work, digital communication tools, shared documents, and collaborative platforms
2.3	Inquiry & Experimentation	Digital tools enabling scientific inquiry, virtual experimentation, modeling, and investigation, including virtual experiments, digital investigation tasks, modeling activities, and exploration of scientific phenomena
2.4	Knowledge Presentation	Tools used to present, visualize, demonstrate, or represent scientific knowledge, including digital animations, visualizations, presentations, diagrams, and multimedia explanations
2.5	Resource Access & Lesson Organization	Tools facilitating lesson preparation, distribution of learning materials, and organization of learning activities, including learning portals, resource repositories, digital lesson plans, and organizational tools for instruction

Drawing on these dimensions, the study established a coding framework consisting of five ICT tool categories and five pedagogical functions. The tool categories were display and investigation technologies, information technologies, connectivity technologies, data technologies, and general digital technologies. The pedagogical functions included assessment and feedback, collaboration and communication, inquiry and experimentation, knowledge presentation, and resource access and lesson organization. This typology allowed each reference to ICT in the curriculum documents to be coded twice: once according to the technology type and once according to its pedagogical purpose. The study applies the dual typology presented in Table 1, which defines the five ICT tool categories and five pedagogical functions used to code all excerpts (Hora & Holden, 2013; Savec, 2017; Webb, 2005).

The analysis involved several stages. First, all curriculum documents were examined. Every reference to ICT, digital tools, or digitally mediated pedagogical processes was identified and extracted. Second, each reference was assigned one code from the tool category set and one code from the pedagogical function set. Third, coding decisions were reviewed iteratively to ensure internal consistency and alignment with the definitions derived from the literature. Fourth, the coded excerpts were entered into a matrix to systematically examine the frequencies of tool types, pedagogical functions and their co-occurrences. This process revealed not only the prevalence of each category but also the combinations through which curricula position ICT within science teaching. Reliability was strengthened through repeated cross-checking of codes and revisiting ambiguous excerpts. Consistency was achieved by applying a single analytical framework uniformly across all documents.

Validity was ensured through the grounding of coding decisions in established literature and the transparent structure of the coding matrix. Together, these procedures ensured that the analysis provided a credible and coherent representation of how ICT is conceptualized within the curricula studied (Cohen et al., 2017; Hennessy et al., 2007).

4. Findings

The analysis of 21 national science curricula generated 133 coded excerpts, summarized in Table 2. The distribution of codes reveals clear patterns in how curricula conceptualize the role of ICT in science education (Gezer & Durdu, 2025; Masters et al., 2015).
Regarding the first research question, references to display and investigation technologies (n = 51) were most frequent across all documents, indicating that ICT is strongly associated with tools that support observation, measurement, and practical investigation. References to general digital technologies were the second most frequent (n = 38), as many curricula referred broadly to "technology" or "digital tools" without specifying a particular device or platform. Mentions of information technologies (n = 15), connectivity technologies (n = 15), and data technologies (n = 14) were less frequent but appeared across multiple documents, suggesting a more selective curricular use of tools related to communication, online content, and data processing (Hora & Holden, 2013; Khairullina et al., 2023).
Regarding the second research question, ICT was most commonly linked to resource access and lesson organization (n = 53). This indicates that technology is primarily framed as a means of accessing information and organizing learning. The second most common function was inquiry and experimentation (n = 34), reflecting a curricular emphasis on using ICT to extend or enhance scientific investigation. Knowledge presentation (n = 22) also emerged as a frequent function, involving digital media for explaining or visualizing scientific concepts. Meanwhile, references to ICT for collaboration and communication (n = 16) and especially assessment and feedback (n = 8) were limited (Masters et al., 2015; Shofiyah et al., 2025).

Table 2: Matrix of ICT Tool Categories and Pedagogical Functions Identified in National Science Curricula

Codes	**2.1**	**2.2**	**2.3**	**2.4**	**2.5**	**Row Total (Total Codes)**
1.1	3	4	16	9	19	51
1.2	0	1	2	7	5	15
1.3	1	5	3	1	5	15
1.4	1	4	5	2	2	14
1.5	3	2	8	3	22	38
Column Total (Total Codes)	8	16	34	22	53	Grand Total: 133

The cross-tabulation of ICT tool types and pedagogical functions shows several strong associations. Display and investigation technologies were most frequently linked with inquiry and experimentation (n = 16) and resource access and lesson organization (n = 19), confirming their central role in supporting practical science work. Information technologies were primarily associated with knowledge presentation (n = 7), reflecting their use in conceptual explanation and scientific communication. Meanwhile, connectivity technologies were most often linked to collaboration and communication (n = 5), consistent with their networking affordances. Data technologies were associated with multiple functions, but they showed the strongest connection to inquiry and experimentation (n = 5). Finally, general digital technologies were aligned overwhelmingly with resource access and lesson organization (n = 22), indicating that broad, non-specific ICT references tend to denote infrastructural or organizational uses rather than discipline-specific scientific activity.
Overall, the findings indicate that national science curricula conceptualize ICT primarily as a means to support inquiry, organize or access resources and present scientific knowledge. However, more functions such as digital assessment or structured collaboration remain less articulated, suggesting that the curricular role of ICT in science education is still developing and unevenly defined across pedagogical intents (Gezer & Durdu, 2025; Masters et al., 2015; Shofiyah et al., 2025; Webb, 2005).

5. Discussion

The analysis of the curricula across 21 education systems revealed a broad but uneven integration of ICT tools and related teaching processes. Overall, ICT appeared frequently across documents, yet references concentrated largely on general digital tools, display and investigation technologies, and resource access tools, while more specialized scientific technologies and advanced data-related tools were mentioned less frequently. This pattern reflects international evidence that curriculum frameworks tend to emphasize ICT as a general-purpose enabler rather than as a discipline-specific cognitive tool (Webb, 2005; Baggott La Velle et al., 2003). Within the first typology, categories such as *display technologies*, *general digital tools*, and *resource access and lesson organization tools* saw some of the highest frequencies, suggesting that many curricula conceptualize ICT predominantly as a means to support presentation, organization, and access to information, rather than as a transformative medium for modeling, simulation, or inquiry. This imbalance aligns with research indicating that, despite the recognized potential of ICT to create rich investigative environments, many systems continue to adopt ICT in ways that primarily streamline existing practices rather than fundamentally reshape pedagogy (Hennessy et al., 2007; Savec, 2017; Tsivitanidou et al., 2021).

Across the second typology, references to inquiry processes, collaboration, and resource management appeared prominently, indicating that many curricula position ICT within broader pedagogical shifts toward student-centered, inquiry-oriented learning. However, the distribution of codes suggests that capabilities for ICT to mediate higher-order scientific processes, such as complex modeling, data interpretation, and conceptual change, remain comparatively underrepresented. This resonates with Webb's (2005) observation that while ICT affords distinct opportunities for cognitive acceleration, authentic inquiry, and formative assessment, these require curricula that explicitly frame ICT as part of students' disciplinary reasoning rather than as a peripheral support system. The matched matrix further highlights that curricula frequently link ICT with inquiry, communication, and resource organization, but it is associated less often with assessment or scientific data practices, despite these being domains where digital tools have shown strong learning benefits. The particularly limited emphasis on ICT-supported assessment and feedback deserves closer attention. Digital technologies are uniquely positioned to support formative assessment through immediate feedback, adaptive questioning, and iterative revision cycles, all of which are central to inquiry-based science learning. Their marginal presence in many curricula may reflect a persistent separation between assessment policy and digital pedagogy, where technology is framed primarily as a delivery or exploration tool rather than as a mechanism for evidencing and refining understanding. This underrepresentation could limit opportunities for developing data-informed instructional practices that align assessment with scientific reasoning processes (Dini et al., 2024; Gezer & Durdu, 2025; Shofiyah et al., 2025).

An important pattern emerging from the dataset is the consistently high coding for several curricula across both typologies, indicating a systematic and pedagogically coherent integration of ICT. In these documents, ICT was positioned not only as a means of accessing resources or facilitating communication but also as a core component of inquiry processes, data practices, and scientific reasoning. Such coherence reflects broader policy shifts toward technology-supported authentic science learning. In contrast, other curricula contained only occasional or fragmented references to ICT, suggesting a more instrumental or administrative conception of digital technologies. This variation aligns with wider discussions on curricular coherence, teacher professional autonomy, and system strategies (Hora & Holden, 2013; Hennessy et al., 2007).

Another notable aspect concerns the degree of specificity with which ICT is described across curricula. Several documents relied on broad or umbrella terms—such as digital tools, technological resources, or ICT competence—without clarifying which technologies or pedagogical applications these encompass. This lack of specificity may reflect curriculum design traditions that prioritize flexibility and local autonomy, allowing teachers or schools to determine the most suitable digital tools for their contexts. However, such open formulations risk diminishing the disciplinary role of ICT by obscuring how particular technologies can support scientific inquiry, data-focused reasoning, or conceptual progression. Conversely, curricula that provided more explicit descriptions of ICT tools and pedagogical applications tended to articulate clearer expectations regarding inquiry processes, modeling, data manipulation, and communication. This divergence suggests that curricular coherence is shaped not only by the frequency of ICT references but also by the clarity with which digital tools and practices are embedded within scientific learning goals, influencing teacher enactment and students' opportunities to engage with the epistemic practices of science (Hora & Holden, 2013; Savec, 2017; Khairullina et al., 2023; Masters et al., 2015; Rogoza et al., 2024; Shofiyah et al., 2025).

Taken collectively, these findings indicate that while ICT is widely recognized within contemporary science curricula, its pedagogical role varies substantially. The prevalence of references to ICT as a general-purpose enabler suggests that many policies still conceptualize ICT primarily as an infrastructure for delivering content and supporting teaching. Meanwhile, explicit guidance on leveraging ICT to advance scientific inquiry, data-driven reasoning, modeling, and conceptual development appears less common, despite substantial evidence of its impact on scientific learning. The study thus underscores a gap between the transformative learning opportunities afforded by ICT and the way they are articulated in national policy documents (Webb, 2005; Savec, 2017).

6. Conclusion

The analysis of ICT-related content across 21 national science curricula shows that digital tools are widely acknowledged as integral to contemporary science education, yet their pedagogical role is often underdeveloped. While many curricula make frequent references to general digital tools, presentation technologies, and online resources, far fewer provide explicit guidance on how ICT can support core scientific practices such as inquiry, data analysis, modeling, or critical reflection. Despite the increasing availability of digital technologies, curricula frequently position ICT as a supplementary resource rather than as a catalyst for deeper engagement with scientific reasoning. This pattern reinforces findings in the wider literature, which emphasizes that the transformative power of ICT emerges not from its presence but from its purposeful alignment with the epistemic practices of science (Webb, 2005; Savec, 2017; Hennessy et al., 2007).

The implications of these findings are significant for both curriculum design and teacher education. Curricula that reference ICT only in general or vague terms may leave teachers without clear pedagogical direction, limiting opportunities to integrate digital tools in ways that enhance conceptual understanding, support collaborative learning, or strengthen formative assessment. In contrast, curricula that embed ICT within specific scientific processes provide clearer pathways for teachers to foster digitally mediated inquiry and cultivate problem-solving environments. Policymakers should therefore aim to refine curricular language so that ICT is situated not only as a competency but also as an enabler of disciplinary engagement. At the same time, teacher education programs must equip future teachers with pedagogical strategies for implementing technology-rich science learning, ensuring coherence between curricular expectations, instructional practices, and system-level supports. These conclusions align with research highlighting the importance of deliberate, pedagogically grounded integration of ICT in science education (Hora & Holden, 2013; Baggott La Velle et al., 2003; Dini et al., 2024).

While this study provides valuable insights, several limitations must be acknowledged. The analysis is restricted to written curriculum documents and therefore does not capture how ICT expectations are interpreted or enacted by teachers, nor does it account for differences in infrastructure, policy environments, or local digital capacities. The coding framework, although systematic, necessarily reduces the complexity of curricular language and may not fully reflect subtle pedagogical intentions. Additionally, the study does not examine learning outcomes or classroom practices, which are essential for understanding the real impact of ICT on science learning. These limitations present opportunities for further research into teacher perspectives, student experiences, and the alignment between curricular aspirations and classroom realities (Cohen et al., 2017; Gezer & Durdu, 2025; Huang et al., 2021; Masters et al., 2015; Khairullina et al., 2023).

This study provides insights into how ICT is framed within national science curricula. The findings reveal a need for more explicit, pedagogically oriented integration of digital tools, emphasizing not only what technologies are included but also how they are intended to support scientific thinking and practice. As digital technologies continue to shape scientific work and social participation, strengthening the curricular embedding of ICT represents an important step toward fostering scientifically literate, digitally capable learners who can engage critically and creatively with technology-rich scientific environments (Gezer & Durdu, 2025; Shofiyah et al., 2025; Rogoza et al., 2024; Rayan et al., 2023).

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