

Review

# Coeducation in Digital Competence and Data Science: A Conceptual Alignment Study

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## Abstract

In the European context, promoting digital competence across society has had a widespread impact at all levels of the education system, leading to multiple regulatory developments according to their scope: citizens' digital competence, teachers' digital competence, and the digital competence of educational organizations. Likewise, Data Science has gained prominence in higher education and research and is now commonly described as the fourth paradigm of science. This conceptual paper examines the connections between citizens' digital competence and Data Science Education. To do so, it draws on the DigComp 2.2 framework for citizens' digital competence, the Reference Framework for Teachers' Digital Competence (MRCDD, from its Spanish acronym), and the data cycle, a theoretical lens frequently adopted in educational research on Data Science. Beyond the fact that data constitute a core component of digital competence and that Data Science demands an advanced development of this competence, we identify a strong alignment between the digital-competence reference frameworks and the theoretical framework underpinning Data Science Education. In addition, we pinpoint an area for improvement in order to achieve comprehensive preparation in both domains, emphasizing the need to incorporate aspects related to environmental sustainability, health, and well-being. Framed through the lens of Whole Schooling, these connections underscore the need for coordinated, schoolwide efforts toward equitable digital and data education, including coeducational strategies that support gender equity in Data Science learning. In addition, we outline equity-by-design implementation principles, addressing accessibility, differentiated pathways, and digital-divide mitigation, so that integrated digital competence and Data Science learning opportunities are realistically available to all students, including those with disabilities, multilingual backgrounds, and socio-economically disadvantaged contexts. Finally, we propose that compulsory education integrate this training to strengthen citizens' digital competence while also providing an initial pathway toward the more specialized technological profiles that society demands across all areas of knowledge.

**Keywords:** digital transformation; digital competence; data science education; data cycle; educational research

## Introduction

The rapid penetration of technology into our personal, social, economic, and professional spheres, and its accelerated growth across all aspects of life, calls for coordinated action from all sectors of society. The scope of this transformation is such that digital transformation has become, in alignment with the 2030 Sustainable Development Goals (United Nations [UN], 2015) and the Digital Europe Programme 2021–2027 (European Commission [EC], 2018), one of Europe's thematic priorities. In Spain, this agenda has been promoted by the Ministry of Economic Affairs and Digital Transformation. This emphasis intensified after the pandemic through the Recovery, Transformation and Resilience Plan (Government of Spain [GoS], 2021), which also brought existing shortcomings to light.

Within this digital transformation, data play a fundamental role as a means of generating knowledge across all areas of society. Understanding how data are produced, collected, processed, and transformed into knowledge, including structured



and unstructured data, at varying volumes, in any format (images, video, audio, text, ...), and how they are disseminated is increasingly valued both in personal contexts and in the labor market, including the scientific sector. Consequently, Data Science has positioned itself as an essential discipline for personal development and for virtually any professional activity.

Accordingly, bringing together the education system's drive to strengthen citizens' digital competence with the preparation of digital professionals, this paper explores the connections between Data Science Education and the Digital Competence Framework.

In the digital transformation in which we are currently immersed, the education system takes on a dual and fundamental role. Digital transformation is increasingly enacted in schools through multiple, interdependent levers, curriculum, pedagogy, professional learning, infrastructure, assessment practices, and family-community engagement. For this reason, it is best approached as a whole-school improvement process rather than as a collection of disconnected initiatives. In this manuscript, we adopt Whole Schooling as an organizing lens, particularly Principle 2 (Create learning spaces for all), Principle 3 (Include all in learning together), Principle 5 (Support learning), and Principle 8 (Use technology to facilitate student learning), to foreground coherence and equity in schoolwide responses to digital transformation, emphasizing the need to align policies, classroom practices, and organizational supports so that all students can benefit (Peterson, 2025).

Within this whole-school framing, coeducation is not treated merely as mixed-gender schooling, but as a commitment to ensuring that girls and boys have equitable access to high-quality learning opportunities in digital and data-rich domains. International evidence points to persistent gender disparities in participation and progression in data-intensive STEM pathways, shaped by stereotypes, differential opportunities, and socio-cultural expectations (United Nations Educational, Scientific and Cultural Organization [UNESCO], 2017; Alan Turing Institute, 2019). Accordingly, the manuscript highlights coeducational implications by considering schoolwide practices aligned especially with Principle 3 (Include all in learning together), as well as Principle 2 (Create learning spaces for all) and Principle 4 (Build a learning community), in order to reduce gendered barriers to engagement and achievement in digital and data-related learning (Peterson, 2025).

This study is a conceptual paper based on qualitative document analysis and a structured crosswalk across frameworks. We analysed DigComp 2.2 (citizens' digital competence); the Reference Framework for Teachers' Digital Competence (MRCDD, from its Spanish acronym), with emphasis on its sixth area; and a widely used data-cycle perspective in Data Science Education (PPDAC/data cycle). Using a shared analytic grid aligned with the phases of data-centric inquiry (problem-plan-data-analysis-conclusion), we mapped correspondences, complementarities, and gaps across the frameworks. The shared analytic grid operationalizes this alignment by using the phases of the data cycle as common reference points and by mapping DigComp 2.2 and MRCDD descriptors to the phase or practice they most directly support. Alignment decisions were guided by four explicit criteria: (i) conceptual equivalence, (ii) functional correspondence to the same phase of the data cycle, (iii) similarity in the intended learner action (e.g., identify, manage, interpret, communicate, or solve), and (iv) compatibility in the level of granularity between descriptors. An illustrative example of this grid and the matching procedure is provided in **Appendix Table 3**. The implications and recommendations presented in this paper are derived from this conceptual mapping (rather than from primary empirical data) and are interpreted through a Whole Schooling lens with explicit attention to equity-oriented implementation conditions.

Beyond gender, equitable participation in digital and data-rich learning is shaped by intersecting factors such as socio-economic status, disability, rurality, migration trajectories, and language background. Research on the digital divide shows that unequal access to devices/connectivity and differences in digital skills can magnify existing offline inequalities unless schools intentionally compensate through targeted provision and inclusive pedagogies (van Dijk, 2020; Hargittai, 2010; Gottschalk & Weise, 2023; van Deursen & van Dijk, 2011; Selwyn, 2004). Therefore, translating the conceptual alignment documented in this paper into practice requires schoolwide planning that addresses access, accessibility, participation, and support structures as core implementation conditions rather than as add-ons.

First, as a key priority, it must provide society with well-prepared professionals capable of addressing the challenges that this transformation poses in the labor market. To this end, a growing number of universities and training centers, both public and private, are incorporating specific undergraduate and/or graduate programs in Data Science into their educational offerings. For example, at the national level in Spain, the University of Navarra, the University of Valencia, and Universidad Carlos III de Madrid, among others, offer a bachelor's degree in Data Science; other institutions provide graduate-level preparation through official master's programs, as is the case at the University of Granada (UGR). Training and research

institutions such as the Andalusian School of Public Health (EASP), as well as private companies such as International Business Machines (IBM) and Oracle, also offer specialized education in this area, either as standalone programs or embedded within broader training initiatives, given its relevance as a tool for decision-making across domains of knowledge. Internationally, many universities likewise include undergraduate degrees in this field, or degree-equivalent programs, such as the University of Buenos Aires and the University of Michigan, among many others.

In parallel, from the stage of compulsory schooling onward, the education system must prepare citizens to engage with this digital transformation and to function effectively in a data-driven society, both in professional settings and in personal life. This entails promoting, among other dimensions, data literacy (Castañeda et al., 2024), critical thinking, and data privacy and ethics. Accordingly, current pre-university curricular regulations in Spain (Royal Decree 157/2022; Royal Decree 217/2022; and Royal Decree 243/2022) align the operational descriptors of graduate profiles (perfiles de salida) with the competence areas identified for citizens' digital competence.

This two-dimensional perspective is reflected in the European Union's Digital Education Action Plan (EC, 2020) and in national initiatives such as the Digital Spain 2026 agenda (GoS, 2022), a cornerstone of Spain's Recovery, Transformation and Resilience Plan (GoS, 2021), whose strategy for addressing the challenge is summarized in Figure 1.

In the aforementioned document, the breadth of actions and programs currently underway is presented as a means of providing the training required to ensure a high-quality and inclusive education and to advance the digitalization of society. In the educational sphere, particularly notable initiatives include Programs for the Digitalization of the Education System, Programs to Enhance Educational Digital Competence, the Plan for the Modernization of Vocational Education and Training, and Digital Citizenship Training, among others.

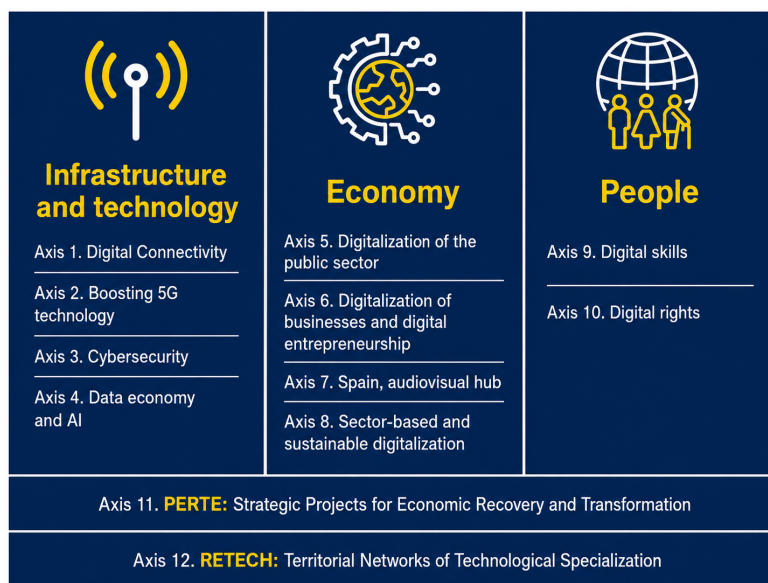


Figure 1. Strategic Axes of the Digital Spain Agenda (Digital Spain 2026).

## Digital Competence

Digital competence was introduced by UNESCO (Søby, 2008) as a multimodal and complex concept that continually evolves alongside the development of digital media and is subject to differing interpretations depending on the perspective adopted. One interpretation emphasizes basic technological skills; a second focuses on the use of those skills as a foundation for professional practice; and a third is oriented toward more specialized digital competence and knowledge.

At present, within the European Union context, digital competence is one of the eight key competences for lifelong learning and is understood as follows:

Digital competence entails the safe, critical, and responsible use of digital technologies for learning, at work, and for

participation in society, as well as engagement with these technologies. It includes information and data literacy, communication and collaboration, media literacy, the creation of digital content (including programming), safety (including digital well-being and competences related to cybersecurity), issues related to intellectual property, problem solving, and critical thinking (Council of the European Union, 2018, p. 9).

This conceptualization, which adopts the aforementioned multidimensional approach, has led to the development of a set of differentiated initiatives grounded in their respective focal areas. Accordingly, the following frameworks have been established through the European Union’s Joint Research Centre (JRC): (i) the European Framework for Citizens’ Digital Competence, DigComp: A framework for developing and understanding digital competence in Europe (Ferrari et al., 2013); (ii) the European Framework for the Digital Competence of Educators, European Framework for the Digital Competence of Educators: DigCompEdu (Redecker & Punie, 2017); and (iii) the European Framework for Digitally Competent Educational Organisations, European Framework for Digitally Competent Educational Organisations-DigCompOrg (Kampylis et al., 2015).

Consistent with these reference points, and in addition to the actions launched under the National Plan for Digital Skills integrated into the Digital Spain 2026 agenda (GoS, 2022), the Plan for the Digitalization and Digital Competences of the Education System (Plan DigEdu) includes, as its first line of action, the development of Educational Digital Competence for: (i) schools, through the development of the School Digital Plan (within the DigCompOrg framework) and the SELFIE tool (Self-reflection on Effective Learning by Fostering the use of Innovative Educational Technologies); (ii) teachers, through the Reference Framework for Teachers’ Digital Competence (MRCDD, within the DigCompEdu framework); and (iii) students, through competence development within the curriculum (within the DigComp 2.2 framework) (National Institute for Educational Technologies and Teacher Training [INTEF], 2023).

Finally, all of the above is reflected in the current education law, LOMLOE (Organic Law 3/2020, of 29 December), in its sole article, specifically, item sixty-two (section 1) and item fifty-seven (section 6), and, by re-enacting Article 83.1 of Organic Law 3/2018, of 5 December, on the Protection of Personal Data and Guarantee of Digital Rights, in its fourth final provision.

## Data Science

Data Science, a term introduced by Cleveland (2001) to expand the technical areas within statistics by focusing on the role of the data analyst, has a broad scope and is difficult to capture in a single definition. Nevertheless, Irizarry’s (2020) definition is useful for conceptualizing it, as it frames Data Science as an umbrella term encompassing multiple areas of specialization, each concerned with the fundamental activity of deriving valid meaning from data. This idea can be visualized in Figure 2, where a hierarchy of knowledge extraction based on data is illustrated—from “Data” to “Wisdom”, which precisely reflects how data science transforms raw data into information, knowledge, and ultimately meaningful understanding within a structured learning process.



Figure 2. Level of Training and Data-Driven Knowledge Extraction.

There is broad consensus that, since the so-called Big Data “boom”, the demand for data scientists has grown to such an extent that it is now considered one of the most sought-after professional profiles by technology companies, research centers, banks, and other organizations. However, beyond the term’s professional relevance, Data Science also carries important implications in the personal sphere. The skills encompassed by this construct are directly applicable to everyday life, including interpretation, contextualization, critical thinking, representativeness, generalization, and ethics, among others. These competencies point to a more general form of education that should be provided from compulsory education onward, fostering data literacy from mathematical, statistical, computational, and domain-specific perspectives.

Nevertheless, there is currently no educational curriculum that develops Data Science within compulsory education. In contrast, initiatives have been proposed in some of the world’s major powers (Biehler et al., 2018; Davies & Sheldon, 2021; IDSSP, 2021; among others), and the need to rethink the practical preparation that students receive at these educational stages is being increasingly explored. The intended reformulation is conceptualized in alignment with the international perspective initiated by Nolan & Temple Lang (2010) and subsequently supported by reports from highly influential institutions, such as: (i) Guidelines for Undergraduate Programs in Statistics (American Statistical Association [ASA], 2014), (ii) Guidelines for Assessment and Instruction in Statistics Education College Report (GAISE) (ASA, 2016), and (iii) Data Science for Undergraduates: Opportunities and Options (National Academies of Sciences, Engineering and Medicine [NASEM], 2018).

Accordingly, this manuscript pursues two complementary aims: (1) to analyse the correspondence between DigComp 2.2, the MRCDD and data-cycle-based frameworks in Data Science Education, and (2) to derive practical, Whole Schooling–informed implementation levers to support equitable access and participation for diverse learners in compulsory education.

## Theoretical Framework

In the context of promoting digital competence from an educational perspective in its multiple dimensions, we focus on the development of citizens’ digital competence and on the teaching competences described in the MRCDD that support the development of students’ digital competence. In addition, we outline the theoretical framework commonly used to study Data Science Education.

### Reference Framework for Teachers’ Digital Competence (MRCDD)

The MRCDD (Ministry of Education and Vocational Training and the educational administrations of the autonomous communities [MEFP & AECA], 2022) emerged as an adaptation of the DigCompEdu framework (Redecker & Punie, 2017) to the Spanish context and to teachers’ professional development. It is also aligned with regional, national, and European proposals, converging in the creation of the European Education Area by 2025 (Resolution of 4 May, 2022).

As in the European model, the MRCDD is organized into three blocks (teachers’ professional competences, teachers’ pedagogical competences, and teaching competences for professional development), which structure the six areas that comprise the framework (professional engagement, digital resources, teaching and learning, assessment and feedback, empowering learners, and facilitating learners’ digital competence) (MEFP & AECA, 2022). The model of teachers’ progression within this reference framework is structured into three stages (A-access, B-experience, and C-innovation), with two levels per stage (1-initial and 2-consolidation/deepening), for each of the 23 competences that specify these six areas in the Resolution of 4 May, 2022, issued by the Directorate-General for Evaluation and Territorial Cooperation.

Focusing on its implications for the development of students’ digital competence (Marín et al., 2021), and without examining its underlying connections with the other areas, we list below the breakdown of the sixth area into the competences that should be developed and assessed in students:

- Media and information/data literacy
- Digital communication and collaboration
- Content creation
- Responsible use and digital well-being

- Problem solving

Equitable implementation depends on complementary teaching competences captured in the MRCDD/DigCompEdu architecture, particularly those related to empowering learners through accessibility, differentiation, and inclusion. This is relevant because competence alignment alone does not guarantee equitable learning opportunities unless pedagogical and organizational supports are explicitly designed for learner variability.

### Reference Framework for Citizens' Digital Competence

The DigComp 2.2 Reference Framework for Citizens' Digital Competence (Vuorikari et al., 2022) organizes digital competence into five dimensions: the five competence areas (Dimension 1), the set of competences that define digital competence (Dimension 2), and proficiency levels (Dimension 3) (from basic Level 1 to highly specialized Level 8), together with examples of knowledge, skills, and attitudes, as well as use-case examples (Dimensions 4 and 5), for each competence. Figure 3 presents the configuration of digital competence into competence areas and their associated competences in the DigComp 2.2 framework.

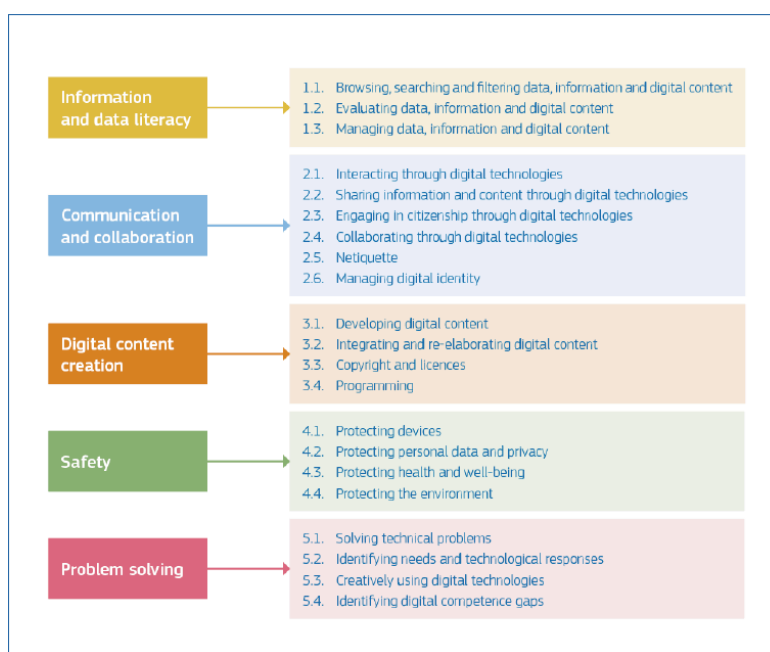


Figure 3. Configuration of digital competence into competence areas and their associated competences in the DigComp 2.2.

### Digital Competence Framework for Citizens

On the other hand, citizens' digital competence in the educational sphere is reflected in the current curricula developed under the LOMLOE framework. Thus, the process of digital literacy begins in early childhood education. It is subsequently specified for the remaining stages (primary, lower secondary, and upper secondary education) through the graduate profile (perfil de salida), by means of five operational descriptors that correspond to the competence areas described in Dimension 1 of the DigComp 2.2 framework. The operational descriptors for the three stages are shown in Table 1.

### Theoretical Framework for Data Science Education

Research in Data Science Education is commonly grounded in the PPDAC model (Problem, Plan, Data, Analysis, and Conclusion), originally devised for teaching industrial statistics by MacKay & Oldford (1994). More specifically, studies tend to rely on adaptations of this model, such as: (i) the PPDAC investigative cycle, described by Wild & Pfannkuch (1999) as the first of four dimensions in their framework for statistical thinking in empirical inquiry; (ii) the data cycle, developed within the context of instruction and assessment in Statistics Education and presented in the GAISE report by Franklin et al. (2007); and/or (iii) the basic cycle of learning from data, reformulated in GAISE II (Bargagliotti et al., 2020),

**Table 1. Operational descriptors in the graduate profile.**

Upon completing Primary Education, the student...	Upon completing compulsory basic education, the student...	Upon completing the Baccalaureate (Bachillerato), the student...
<p>CD1. Conducts guided internet searches and uses simple strategies for the digital processing of information (keywords, selection of relevant information, data organization, etc.), adopting a critical stance toward the content obtained.</p>	<p>CD1. Conducts internet searches using criteria of validity, quality, timeliness, and reliability; critically selects results and archives them in order to retrieve, reference, and reuse them, while respecting intellectual property.</p>	<p>CD1. Conducts advanced searches by understanding how internet search engines work; applies criteria of validity, quality, timeliness, and reliability; critically selects results and organizes information storage appropriately and securely for subsequent referencing and reuse.</p>
<p>CD2. Creates, integrates, and reworks digital content in different formats (text, table, image, audio, video, software application, etc.) using various digital tools to express ideas, emotions, and knowledge, while respecting intellectual property and the copyright of any content reused.</p>	<p>CD2. Manages and uses their personal digital learning environment to build knowledge and create digital content through information-processing strategies and the use of different digital tools, selecting and configuring the most appropriate option according to the task and their lifelong learning needs.</p>	<p>CD2. Creates, integrates, and reworks digital content individually or collaboratively, applying security measures and consistently respecting digital authorship rights in order to expand resources and generate new knowledge.</p>
<p>CD3. Participates in school activities or projects using digital tools or virtual platforms to build new knowledge, communicate, work cooperatively, and share data and content in restricted, supervised digital environments safely, with an open and responsible attitude toward their use.</p>	<p>CD3. Communicates, participates, collaborates, and interacts by sharing content, data, and information through digital tools or virtual platforms, and responsibly manages their actions, presence, and visibility online in order to exercise active, civic, and reflective digital citizenship.</p>	<p>CD3. Selects, configures, and uses digital devices, tools, applications, and online services and incorporates them into their personal digital learning environment to communicate, work collaboratively, and share information, responsibly managing their actions, presence, and visibility online while exercising active, civic, and reflective digital citizenship.</p>
<p>CD4. Understands risks and, with teacher guidance, adopts preventive measures when using digital technologies to protect devices, personal data, health, and the environment, and begins to develop habits of critical, safe, healthy, and sustainable use of these technologies.</p>	<p>CD4. Identifies risks and adopts preventive measures when using digital technologies to protect devices, personal data, health, and the environment, and to become aware of the importance and need to use these technologies in a critical, legal, safe, healthy, and sustainable manner.</p>	<p>CD4. Assesses risks and applies measures when using digital technologies to protect devices, personal data, health, and the environment, and uses these technologies in a critical, legal, safe, healthy, and sustainable manner.</p>
<p>CD5. Begins to develop simple and sustainable digital solutions (reuse of technological materials, block-based programming, educational robotics, etc.) to solve specific problems or challenges creatively, seeking help when necessary.</p>	<p>CD5. Develops simple software applications and creative, sustainable technological solutions to solve specific problems or respond to proposed challenges, showing interest and curiosity about the evolution of digital technologies and their sustainable development and ethical use.</p>	<p>CD5. Develops innovative and sustainable technological solutions to meet specific needs, showing interest and curiosity about the evolution of digital technologies and their sustainable development and ethical use.</p>

Source: Royal Decree 157/2022, Royal Decree 217/2022, and Royal Decree 243/2022.

which provides a framework for Statistics and Data Science Education.

For conceptual clarity, this manuscript distinguishes between Data Literacy and Data Science Education. Data Literacy is understood here as the foundational competence to read, work with, critically interpret, and communicate with data, including basic awareness of data quality and ethical use (Wolff et al., 2016). By contrast, Data Science Education is used in a broader sense to denote an educational field and set of learning goals that build on data literacy but extend it through the data cycle, integrating statistical and computational thinking in order to support data handling, analysis, and communication for inquiry and decision-making (Gould, 2021).

Elaborating on the first dimension proposed by Wild & Pfannkuch (1999), a PPDAC cycle addresses the abstraction and solution of a statistical problem derived from a broader “real-world” problem. This approach distinguishes five phases, consistent with the PPDAC model described by MacKay & Oldford (1994), and highlights its cyclical structure, as illustrated in Figure 4.

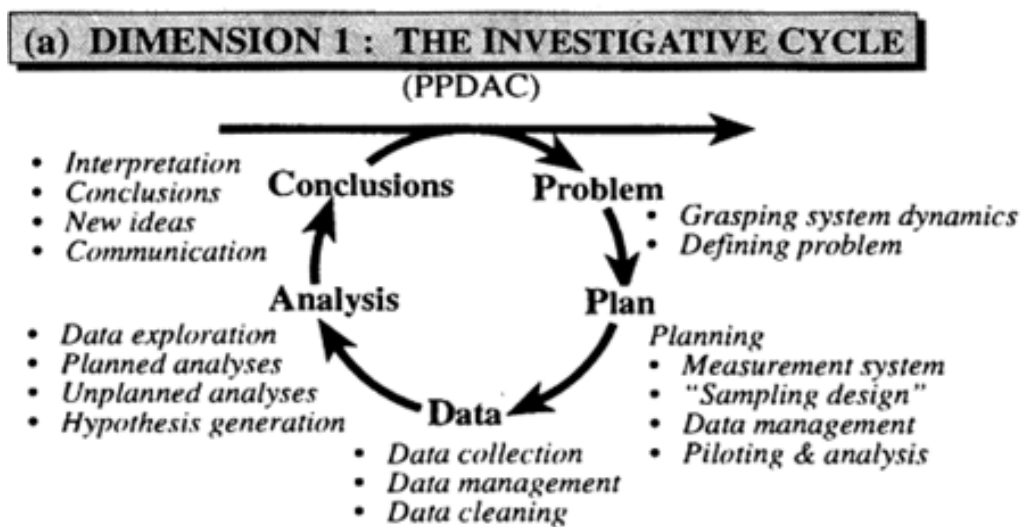


Figure 4. The PPDAC investigative cycle.

In Data Science, both the phases described above and the cyclical structure are especially relevant. Thus, beyond the emphasis that statisticians have traditionally placed on the PPD phases (problem, plan, and data) in the work of the aforementioned authors, this discipline focuses on deriving valid meaning from data (Irizarry, 2020), bringing together Statistics Education with mathematical competencies and a strong computational component. Moreover, its cyclical nature makes it possible to be less concerned with generating and collecting new data, unless the inquiry specifically requires it, and instead to concentrate on extracting knowledge from data that are already being produced. This shift has foregrounded work with authentic data of different types, often raw and drawn from diverse sources, as well as data preprocessing and mining, scalability, machine-learning techniques, the use of multiple programming languages, software and specialized environments for visualization, and a broad engagement with data ethics, including attention to data provenance.

In the same vein, curricular guidelines for undergraduate Data Science programs (De Veaux et al., 2017, pp. 5–9) identify six key competences:

- Analytical thinking (computational and statistical)
  - o Statistical thinking in a data-rich environment
  - o Computational thinking
  - o Integration of approaches
- Mathematical foundations

- Model building and assessment
  - Informal modeling
  - Formal modeling
- Algorithms and software foundations
- Data curation
  - Data preparation
  - Data management
- Knowledge transfer: communication and responsibility

Developing these competences requires integrating topics and tools that have traditionally been presented in isolation, giving rise to six main thematic areas of specialization in Data Science Education:

- Data description and curation
- Mathematical foundations
- Computational thinking
- Statistical thinking
- Data modeling
- Communication, reproducibility, and ethics

## Results

In what follows, we identify potential links between Data Science Education and the Reference Framework for Citizens' Digital Competence, as well as their educational promotion, while also highlighting characteristic features of each.

As an initial approximation, it is noteworthy that multiple conceptions have been proposed for both constructs, emphasizing their multifaceted, complex, and evolving nature, and that both incorporate the safe, critical, and responsible use of technologies. Likewise, both have been the object of rigorous international study with immediate implications for everyday life. On the one hand, digital competence has undergone substantial regulatory development, with various programs established for its promotion, multiple reference frameworks formulated (UNESCO, 2011; Ferrari et al., 2013), and its inclusion as a compulsory element in the current pre-university curricular regulations under the LOMLOE framework (Royal Decree 157/2022; Royal Decree 217/2022; and Royal Decree 243/2022). On the other hand, Data Science has had a major impact on the labor market, emerging as the fourth paradigm of science (Hey et al., 2009; Carriegos, 2018), with immediate implications for Higher Education, alongside initiatives in educational research supported by theoretical frameworks linked to the investigative method (MacKay & Oldford, 1994; Wild & Pfannkuch, 1999; Franklin et al., 2007; Bargagliotti et al., 2020; among others).

From the above, one can infer the distinct impact of each construct on the education system depending on the academic level under analysis. Digital competence, on the one hand, has developed reference frameworks for different sectors of the education system (schools, teachers, students, and citizens), permeating current pre-university curricular regulations. Data Science, on the other hand, has been promoted primarily in Higher Education, and at the pre-university level has been addressed mainly through educational research and the development of curricular guidelines for a potential curriculum in the field.

Despite the divergence in the regulatory evolution of both constructs and their initial treatment at different educational stages, examining the relationship between these theoretical approaches in the context of compulsory education could make it possible to align efforts toward their joint promotion.

## **Citizens' Digital Competence From a Data Science Education Perspective**

The five competence areas identified in the DigComp 2.2 framework are analyzed through the lens of Data Science Education. To this end, we adopt the theoretical frameworks commonly used in Data Science education research described above, together with the development of the curricular guidelines presented and an understanding of the knowledge domain and professional practice.

### ***Information and Data Search and Management***

Within digital competence, a distinction is made among data, information, and digital content. In this context, data are the discrete, basic units of information that must be processed and contextualized to acquire meaning; information is the interpretation and meaning of data in a specific context or for a particular purpose; and digital content is understood as information, media, or material that is presented and distributed in electronic format.

In a broader sense, data are defined as “information about something specific that enables its exact knowledge or serves to deduce the consequences derived from a fact” (Royal Spanish Academy [RAE], 2023). From this perspective, information and digital content could also function as the basic unit from which to construct new information or knowledge. Therefore, from a Data Science Education standpoint, this first competence area would focus on identifying available relevant data (browsing, searching, and filtering), critically evaluating them, and managing them. A direct relationship can thus be observed with the Data phase in the PPDAC cycle, specifically its components of data collection and data management, since, beyond its digital emphasis, searching for and selecting data is part of the investigative cycle.

Analogously, within the recommended curricular guidelines for Data Science, this first competence area aligns with data curation (data preparation and data management).

### ***Communication and Collaboration***

Although an initial approach might relate this competence area to communication in the conclusion stage of the PPDAC cycle, such an association is not straightforward because communication within the latter has typically been conceptualized as unidirectional. Thus, whereas in Data Science Education communication has traditionally been linked to knowledge transfer or dissemination associated with research results, the concept of communication in digital competence is directly associated with establishing interactions through digital technologies.

Nevertheless, even if not made explicit in the theoretical framework of the data cycle considered, effective communication is a fundamental skill for data scientists. This is captured by De Veaux et al. (2017) in the sixth key competence for Data Science Education, “knowledge transfer: communication and responsibility.” For this professional profile, communication is required not only within the work team but also with other production areas and directly with society. It should be noted that, within the data scientist’s scope of practice, beyond providing accessible information to support decision-making, there is also involvement in seeking projects and building models that contribute solutions to those inquiries. In other words, the profile requires a wide range of communication skills in any format (oral, written, visual, graphical, or tabular) and also through digital technologies, at any point in the project lifecycle, from design through implementation. Consequently, it follows that Data Science Education should foster these skills as part of the teaching–learning process in the subject.

### ***Digital Content Creation***

As noted above, Data Science entails a strong computational component. In this regard, programming, as well as the development, integration, and reworking of digital content, are expected competences at an advanced level for this professional profile. Likewise, authorship rights (copyright) and intellectual property licensing are issues associated with data ethics, which is widely addressed in the study of this field. Consequently, all the competences described for this digital-competence area are developed within Data Science Education.

In addition, within the reference investigative cycle (Wild & Pfannkuch, 1999), any of its stages lends itself to content creation, which is now typically presented in digital formats, even if not strictly required by any given stage. Evidence of this can be seen in how research findings are communicated. Traditionally, these findings have involved graphical and/or tabular representations, which are now further enhanced by the development of tools for this purpose. Increasingly, research

also collects data interactively through applications, applets, questionnaires, and other digital instruments, and engages in open science by making data available to other researchers. This also includes work that develops software, packages, or interfaces that form part of the computational techniques used by researchers.

Therefore, whether due to its computational orientation, the theoretical model it commonly adopts, or its original genesis, Data Science Education is oriented toward generating knowledge from data. At the same time, digital content has become the dominant medium for access to, transmission of, and continual updating of all types of knowledge, making both constructs strongly interconnected.

### ***Safety***

Analogously to the previous competence area, data protection, privacy, and device protection are assumed to be developed at a very advanced level in the data scientist profile.

From another standpoint, given the extensive ethical and regulatory development related to data, Data Science Education should also promote environmental protection, health, and well-being. These dimensions are especially relevant in the early educational stages for addressing undesirable digital behaviors such as cyberbullying, violations of netiquette, or basic issues such as ergonomics and screen use.

The link between Data Science Education and environmental sustainability, health, and well-being can be made explicit through the inquiry cycle itself. In PPDAC-style approaches, sustainability-related issues can frame the problem and planning phases (e.g., energy use, air quality, heat exposure, mobility, or waste), while authentic datasets provide the basis for data collection and analysis. This also creates a natural bridge to the Safety domain, since students must address data quality, responsible data use, privacy, and ethical communication when working with real-world data. In this way, environmental sustainability, health, and well-being are not external additions to Data Science Education, but meaningful contexts through which digital competence and data practices can be developed in an integrated way.

In curricular terms, this integration can be operationalized through school-based data investigations such as: (a) analysing school energy consumption before and after efficiency measures; (b) examining local air-quality or mobility data (from sensors or municipal open-data portals) to study patterns and possible health implications; and (c) exploring temperature records or heat-wave trends to communicate evidence-based recommendations for student well-being. These examples align with the data cycle phases and show how environmental sustainability, health, and well-being can be incorporated into compulsory education through practical, data-rich inquiry tasks.

However, none of these issues is reflected explicitly in the PPDAC cycle, nor in the curricular guidelines analyzed, although they could be incorporated within the sixth main thematic specialization area in Data Science Education.

### ***Problem Solving***

The four competences encompassed by this digital-competence area (Figure 3) are included within the fourth key competence described by De Veaux et al. (2017) for Data Science Education, “Algorithms and software foundations.” This competence includes, beyond algorithmic skills and the use of different problem-solving strategies, the implementation of solutions using appropriate high-level programming languages, as well as understanding and maintaining the structures, software, libraries, and packages that data scientists create and use to solve computational problems.

## **The sixth MRCDD Component From a Data Science Education Perspective**

In a logical and unavoidable way, the sixth area of the MRCDD, devoted to the development of students’ digital competence, converges with the Reference Framework for Citizens’ Digital Competence, as can be seen in Table 2.

Accordingly, what was presented in the previous section is also applicable to this dimension of the MRCDD. The key caveat concerns how these competence areas and their associated competences are promoted through teaching practice. This issue cannot be addressed solely by comparing competences or content across the reference frameworks, because many additional variables inherent to the profession must be considered—for example, the use of different pedagogical approaches, classroom participation dynamics, and even factors that are highly contextual and not fully predictable by educators themselves, such as students’ engagement.

**Table 2. Convergence between DigComp 2.2 and the sixth MRCDD competence area.**

Reference Framework for Citizens' Digital Competence (DigComp 2.2)	MRCDD – Sixth competence area: facilitating students' digital competence
Information and data search and management	Media literacy and information/data literacy
Communication and collaboration	Digital communication and collaboration
Digital content creation	Content creation
Safety	Responsible use and digital well-being
Problem solving	Problem solving

Source: [Vuorikari et al. \(2022\)](#); [MEFP & AECA \(2022\)](#).

## Discussion

This paper posits a strong relationship between citizens' digital competence and Data Science Education. This linkage is examined through a comparison of their different conceptualizations, an assessment of the evolution of both constructs, and an analysis grounded in the reference frameworks considered. The findings point to interconnected aims that should be coordinated by the education system during compulsory schooling, enabling the joint development of Data Science Education and citizens' digital competence.

This conceptual alignment is also supported by documented examples of curriculum integration reported in secondary literature. For instance, the Mobilize "Introduction to Data Science" (IDS) curriculum has been implemented as a yearlong secondary-school course, combining statistical and computational thinking with authentic data and highlighting practical conditions such as teacher professional development, infrastructure, and the participation of heterogeneous student groups ([Gould et al., 2016](#)). In addition, lower-secondary teaching proposals have shown how environmental data can be used as a meaningful entry point for Data Science Education, enabling students to work with socio-environmental questions through data collection, analysis, and interpretation in school settings ([Podworny et al., 2022](#)).

On the one hand, there is currently a recognized need to reformulate students' preparation by emphasizing the fundamental role of computational thinking in mathematical and statistical thought and reasoning ([ASA, 2014](#); [ASA, 2016](#); [NASEM, 2018](#)), seeking convergence between mathematics and computing within the context of Statistics Education ([Cobb, 2015](#)). Promoting "data-scientific thinking" ([Gould, 2021](#)) through statistical literacy, thinking, and reasoning is no longer sufficient on its own. Rather, these must be connected to complementary mathematical competencies and to computational thinking, which equips students with the skills to explore and understand statistical concepts and prepares them to adapt to a wide range of real-world problems ([Nolan & Temple Lang, 2010](#)). From a computational standpoint, curricular initiatives to date have also recommended that students use technology to explore concepts and analyze data. In education, specialized software such as CODAP ([Concord Consortium, 2024](#)) and TinkerPlots ([Learn Troop, 2024](#)) has been developed to promote critical data reasoning without requiring specialized knowledge of the tools or programming. Likewise, within the educational community, there is a growing trend to promote resources based on professional software such as R ([R Core Team, 2022](#)) and Python ([Python Software Foundation, 2024](#)), through R Markdown ([Allaire et al., 2023](#)) and Jupyter ([Project Jupyter, 2023](#)).

On the other hand, the promotion of digital competence in society has impacted all strata of the education system through multiple regulatory developments. In this regard, efforts have been directed toward strengthening schools' digital competence by providing infrastructure as well as diagnostic tools, and by promoting the development of a School Digital Plan aligned with the autonomous communities. In addition, the MRCDD has been developed to specify the competence areas for teachers' professional development. Based on this framework, different attainment and certification levels have been established, comparable to those already in place for language competence. Finally, the Reference Framework for Citizens' Digital Competence has been explicitly reflected in the operational descriptors of the graduate profile (perfil de salida) in current curricular regulations across educational stages ([Royal Decree 157/2022](#); [Royal Decree 217/2022](#); [Royal Decree 243/2022](#)). It has also been implicitly reflected through the inclusion of concepts such as computational reasoning and thinking, critical analysis of information, information and data literacy, and media education, among others. Its impact, however, has not been merely regulatory: it has also driven changes in the elective course offerings in secondary schools (e.g., Technology and Digitalization in lower secondary education and Information Technology and Knowledge

in the Baccalaureate), as well as a reconfiguration of teaching roles around these areas (e.g., certifying teachers' digital competence level under the MRCDD, appointing ICT coordinators, updating the School Digital Plan, etc.).

Consequently, there are compelling reasons to regard Data Science Education as jointly relevant to the development of citizens' digital competence from compulsory education onward. Beyond the role of data as a tool for generating knowledge across all areas of society, we identified connections between the digital-competence reference frameworks and the theoretical framework considered for Data Science Education, as well as with some of the curricular initiatives described. Moreover, data are a fundamental component of digital competence, and Data Science in turn requires an optimal level of that competence. Thus, in light of the Technological Pedagogical Content Knowledge (TPACK) model, a competence profile for educators in this domain can be assumed to be similar to that of a data scientist—or, at minimum, to entail a high or very high level of digital competence (B2 and above). This implies teachers' expertise in competences, content, tools, and skills in Data Science that are appropriate for fostering students' digital competence. From a more pedagogical perspective, it is also important to note that promoting computational, analytical, and statistical thinking, together with their integration, as emphasized in Data Science Education, supports the acquisition of competences and the learning of tools not as ends in themselves but as means for generating knowledge, thereby fostering meaningful learning.

Finally, and consistent with Whole Schooling principles related to building a caring community and supporting learning, the study highlights dimensions that should be strengthened within Data Science Education, in a manner similar to their promotion within the digital competence framework, such as deeper attention to the Safety area, particularly regarding environmental sustainability, health, and well-being. With an appropriate emphasis on these dimensions, and based on the connections identified, this integrated preparation would strengthen citizens' digital competence and also serve as an initial pathway toward the more specialized technological profiles that society demands across all domains of knowledge.

The documented alignment between DigComp 2.2 and data-cycle-based Data Science Education provides a coherent curricular rationale, but it is a necessary rather than sufficient condition for inclusive uptake. To ensure equitable access for diverse learners, implementation should be approached as a Whole Schooling process that coordinates curriculum, pedagogy, technology, assessment, and family–community partnerships. Concretely: (a) mitigate structural opportunity gaps by ensuring access to devices/connectivity and providing low-tech/offline alternatives when needed; (b) design data investigations with multiple entry points and supports (e.g., multimodal representations, language scaffolds, and flexible ways of demonstrating learning) consistent with Universal Design for Learning [UDL] principles (CAST, 2018; Meyer et al., 2014); (c) organize participation through cooperative structures and rotating roles so that all students can engage meaningfully in each phase of the data cycle (Gillies, 2016; Johnson & Johnson, 2014); and (d) monitor equity through formative assessment and disaggregated participation/achievement evidence to identify and address barriers early (Black & Wiliam, 2009). These levers strengthen the practical applicability of the proposed integration within an inclusive education agenda.

Although the document base used in this study is anchored in Spain/EU policy frameworks (e.g., LOMLOE, DigComp 2.2, MRCDD), the conceptual crosswalk proposed here is transferable to other educational systems. The key step is not to reproduce the same policy instruments, but to apply the same mapping procedure by identifying equivalent frameworks for students' digital competence, teachers' digital/professional competence, and curriculum expectations, and then examining their correspondence with the data cycle (PPDAC). This makes the approach adaptable to contexts such as North America or Asia, where digital competence and technology education may be organized through different curricular and policy traditions. However, adaptation is not automatic: feasibility depends on local curriculum structures, assessment regimes, infrastructure and connectivity, teacher professional development, and data governance and privacy regulations. In addition, equity conditions (e.g., digital access and support for diverse learners) remain central to implementation across contexts. Therefore, this study offers a transferable conceptual alignment model, while recognizing that local educational systems require context-specific adaptation.

This study is conceptual and relies on qualitative document analysis and framework alignment rather than primary empirical data. Therefore, the proposed correspondences should be interpreted as an analytically grounded model and not as evidence of classroom effectiveness. Additionally, the document base used in this study draws on Spain/EU policy frameworks, and transferability to other educational systems requires local re-alignment with equivalent standards, curriculum structures, and data-governance norms. Finally, any crosswalk involves interpretive judgment in coding and matching

the descriptors. Future work should test and refine the proposed alignment through empirical studies (e.g., classroom implementations, teacher professional development cases) and by examining how the framework performs across diverse contexts.

## Conclusions

This paper has examined the relationship between citizens' digital competence and Data Science Education by contrasting their conceptual foundations, tracing their respective policy and curricular trajectories, and analyzing the correspondence between DigComp 2.2, the MRCDD, and data-centric inquiry frameworks commonly used in Data Science Education. Across these lenses, the results indicate a high degree of conceptual and curricular compatibility, suggesting that both domains can be approached as complementary dimensions of a coherent educational agenda in compulsory schooling.

Three main conclusions emerge. First, the analysis shows a substantive alignment between the competence areas of DigComp 2.2 and the capacities emphasized in Data Science Education (e.g., data search and management, communication and collaboration, digital content creation, problem solving, and ethical considerations). This alignment is further reinforced by the convergence between DigComp 2.2 and the sixth MRCDD area focused on developing students' digital competence, which positions teachers as key mediators of integrated learning trajectories.

Second, the findings support the educational pertinence of embedding Data Science Education within the broader development of citizens' digital competence. Beyond labor-market considerations, Data Science-related practices contribute to essential civic and personal capabilities in a data-driven society, including critical interpretation of information, contextual reasoning, representativeness, generalization, and ethical judgment. From a pedagogical standpoint, integrating statistical, mathematical, and computational thinking fosters meaningful learning in which tools and technologies are treated as means for knowledge generation rather than ends in themselves.

Third, the study identifies a clear area for improvement in current approaches: a more explicit and systematic incorporation of environmental sustainability, health, and well-being within Data Science Education, in parallel with the emphasis placed on these dimensions in the Safety area of digital competence frameworks. Strengthening this dimension is particularly important in compulsory education, where preventive and formative aims regarding responsible technology use, digital well-being, and socio-environmental impacts are central.

Finally, the educational value of this integrated agenda depends on equity-oriented implementation: whole-school planning should mitigate digital divides and embed accessibility and differentiated pathways so that students with diverse needs and backgrounds can participate meaningfully in data-driven learning.

Overall, the evidence presented here justifies considering a coordinated educational approach that jointly promotes citizens' digital competence and Data Science Education from compulsory schooling onward. From a Whole Schooling perspective, this coordination should be enacted through schoolwide planning and renewal processes that align curriculum, pedagogy, technology use, family-community partnerships, and assessment with the goal of equity and excellence for all learners (Peterson, 2025). In addition, coeducational implementation requires explicit attention to gender equity so that girls and boys can participate and thrive in data-driven learning pathways (UNESCO, 2017). Such integration would simultaneously enhance broad-based digital competence for all learners and provide an early, inclusive pathway toward the specialized technological profiles increasingly required across domains of knowledge.

## Author Contributions

Conceptualization, EMP and JMCG; methodology, EMP and JMCG; formal analysis, EMP, JMCG, RCL and DMM; investigation, EMP, DMM, RCL and JMCG; resources, EMP; data curation, EMP; writing—original draft preparation, EMP, RCL and JMCG; writing—review and editing, EMP, RCL, DMM and JMCG; visualization, EMP, DMM and JMCG; supervision, EMP; project administration, EMP; contribution to reviewing and proofreading, EMP, JMCG, RCL and DMM. All authors have read and agreed to the published version of the manuscript.

## Ethics Approval and Consent to Participate

Not applicable. This study is based on the analysis and alignment of existing policy documents, reference frameworks, and publicly available curricular guidelines, and did not involve human participants, personal data, or interventions requiring ethics approval or informed consent.

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## Availability of Data and Materials

Not applicable. No new datasets were generated or analyzed in this study. All materials referenced are publicly available documents (e.g., policy reports, competence frameworks, and curricular regulations) cited in the manuscript.

## Conflict of Interest

The authors declare no conflicts of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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## Appendix

**Table 3. Illustrative example of the shared analytic grid.**

DigComp 2.2 area	PPDAC phase/data-cycle reference	Data Science Education interpretation	MRCDD area 6 correspondence	Rationale
Information and data search and management	Data (collection/management)	Identifying relevant data, critically evaluating them, and managing them as part of the investigative cycle	Media literacy and information/data literacy	The three frameworks converge on searching, selecting, evaluating, and managing data as core practices for inquiry.
Communication and collaboration	Conclusion / communication across the cycle	Communicating findings and interacting with others through oral, written, visual, graphical, tabular, and digital forms	Digital communication and collaboration	Communication is central in both frameworks, but in the data-cycle tradition it is more often linked to reporting results, whereas DigComp/MRCDD emphasize interaction through digital technologies.
Safety	Cross-cutting ethics/safety across the cycle	Responsible data use, privacy, ethical communication, and the integration of environmental sustainability, health, and well-being	Responsible use and digital well-being	DigComp/MRCDD address safety explicitly; in Data Science Education, related issues appear indirectly through ethics and responsibility, with limited explicit attention to sustainability, health, and well-being.
Problem solving	Analysis / computational problem solving	Using algorithms, software, and programming-based strategies to solve computational and analytical problems	Problem solving	There is strong correspondence between digital problem solving and the computational foundations required in Data Science Education.

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