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[Ida Cortoni](#)^{*} and [Gianluca Senatore](#)^{*}

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Article

Cultural Sustainability: Soft Competences, Identity and Digital STEAM Education for Inclusive Citizenship in Primary School

Ida Cortoni ¹ and Gianluca Senatore ^{2,*}

¹ Dipartimento di Pianificazione, Design, Tecnologia dell'Architettura, Sapienza Università di Roma, Rome, Italy

² Dipartimento di Scienze Politiche, Sapienza University of Rome, Rome, Italy

* Correspondence: ida.cortoni@uniroma1.it

Abstract

Starting from the assumption that, in contemporary debate, sustainability should increasingly be interpreted within a sociological paradigm, this contribution aims to analyse the soft competences required for the education of a citizen capable of developing an ethical and inclusive orientation, understood as a civic prerequisite for processes of sociocultural integration. From this perspective, sustainability is not considered solely as a set of environmental practices or public policies, but rather as a cultural and normative dispositive that structures habitus, representations and models of action. The progressive acquisition of knowledge, values and practices oriented towards sustainability, both at the individual and collective levels, makes it possible to frame this phenomenon as a constitutive dimension of processes of modernisation and sociocultural development. Such processes are frequently supported and accelerated by technological innovation, which acts as an enabling but not determining factor. Moving beyond deterministic interpretations of a technological, political or economic nature, the analysis adopts a culturalist perspective that emphasises the social construction of a sustainable identity, namely an identity that assumes sustainability as a regulative principle of everyday action and as a lifestyle for the contemporary citizen. This trajectory implies the active and inclusive involvement of agencies of socialisation, first and foremost the school institution, called upon to promote sustainability as a foundational value of social inclusion and community cohesion. Within this framework, the second part of the contribution explores sustainability education through the implementation of a design protocol for digital education within STEAM disciplines, placing particular emphasis on methodologies and tools such as coding and educational robotics, understood as pedagogical tools for the development of critical, collaborative and socially responsible competences.

Keywords: sustainability education; culturalisation; coding; STEAM approach; digital education; social capital

1. Introduction

The concept of sustainability has progressively emerged as one of the main normative and interpretative frameworks in contemporary debate, assuming a central role both in institutional agendas and in scientific reflection. However, this diffusion has not been accompanied by a corresponding theoretical consolidation, resulting in persistent conceptual and applicative ambiguity. Sustainability can thus be understood as a genuinely interdisciplinary field of research (Markard et al., 2012), developed through the integration of innovation studies, sociology, economics and policy analysis.

Sustainability has often been constructed primarily as a response to fears related to environmental risks, rather than as the outcome of a conscious cultural process (Senatore & Groe, 2021). Similarly, its diffusion has been strongly influenced by the perception of threats generated by processes of modernisation. This has produced an emergency-oriented paradigm, in which sustainability is proposed as a response to crisis situations but fails to stabilise as a long-term guiding principle.

For these reasons, a sociological redefinition of sustainability is required, capable of overcoming the emergency-based perspective and recognising its deeply cultural nature. From this viewpoint, sustainability should be interpreted as a process of social construction, where structural changes are inseparable from symbolic and value transformations. The contribution of Moscovici (1961) on social representations is particularly relevant, as it highlights how shared forms of knowledge contribute to the construction of a common reality and to the orientation of collective behaviours. Within this framework, the diffusion and stabilisation of sustainable practices can be interpreted as the outcome of processes of social elaboration and sharing of meanings, through which models of action become progressively familiar and socially legitimised.

Similarly, Bateson (1984) emphasises the need to develop an “ecology of mind”, in which knowledge is not oriented exclusively towards technical production, but towards understanding the systemic relationships between human beings and the environment. This epistemological perspective highlights that sustainability cannot be reduced to a matter of tools or policies but should instead be interpreted as a transformation in ways of knowing and attributing meaning to the world.

Within this context emerges the concept of the culturalisation of sustainability, understood as the process through which sustainability is progressively internalised within cultural systems, shifting from a normative prescription to an interpretative and regulatory principle guiding social action (Senatore, 2014; 2025; Senatore & Groe, 2021). From this perspective, sustainability should be understood as the outcome of a transformation of knowledge systems and cultural models that orient social practices.

As highlighted in recent literature, the transition towards sustainability implies a profound reorganisation of the symbolic and cognitive systems through which societies interpret the relationship between humans, nature and development (Senatore, 2025). This transformation concerns not only the content of knowledge but also the ways in which knowledge itself is produced, transmitted and legitimised.

Within this framework, the concept of culturalisation of sustainability assumes a central role, as it allows sustainability to be interpreted as a process of internalisation of values, practices and knowledge within social systems. This process does not merely involve the diffusion of sustainable behaviours but implies a deeper transformation affecting the symbolic and normative structures of society.

Accordingly, the culturalisation of society in a sustainability-oriented perspective implies new integrated priorities of knowledge, where technical-scientific competences are complemented by humanistic, philosophical and sociological forms of knowledge. This process enables the overcoming of disciplinary fragmentation and supports the development of a systemic understanding of reality, where sustainability is interpreted as a multidimensional construct within a holistic perspective, where human beings are considered an integral part of a broader system of relationships.

Education and Sustainable Citizenship: From Culturalisation to Social Practice

The centrality of the cultural dimension becomes particularly evident when analysing the processes through which sustainability is stabilised. For a transition towards sustainability to acquire effectiveness and long-term stability, sustainability must be integrated into cultural systems and everyday practices. This process of integration occurs through mechanisms of cultural production and reproduction that enable the transmission of values and practices across generations. From this perspective, culture represents a structural condition for sustainability (Senatore, 2025). To

understand the fundamental dynamics of the culturalisation principle, the contribution of Malinowski (1931) is particularly relevant. In his definition of culture, the author describes it as the set of social responses to fundamental needs that are selected, modified or even abandoned, yet always transmitted over time. Applied to sustainability, this perspective highlights how sustainable behaviours can consolidate only through processes of cultural assimilation and institutionalisation.

The analysis developed here shows that sustainability, interpreted as a process of culturalisation, requires an operational translation into processes of education and socialisation. Within this perspective, education assumes a central role, becoming the privileged space through which sustainability-oriented values, knowledge and practices are transmitted, internalised and stabilised over time.

Sustainability should therefore be understood as a cultural structure capable of orienting social action; however, this orientation becomes effective only when it is incorporated into educational systems and processes of cultural transmission (Senatore, 2025). In this sense, education represents the primary mechanism through which culturalisation can be transformed into social practice, contributing to the construction of coherent and durable behavioural models.

Within the framework of the culturalisation of sustainability, education assumes a transformative function, as it contributes to the formation of individuals capable of integrating knowledge, values and practices within a perspective oriented towards social responsibility. As highlighted by Soini and Birkeland (2014), the cultural dimension represents an essential component of sustainability, as it enables the production and transmission of meaning systems that make social practices possible. For these reasons, sustainability must be understood as a complex process oriented towards the development of soft competences. Such competences include the ability to interpret the complexity of social and ecological systems, participate in collective processes and orient action according to shared values.

Sustainability thus becomes an integral part of citizens' identity, contributing to the formation of habitus oriented towards responsibility, cooperation and intergenerational awareness.

Within processes of culturalisation, the school emerges as one of the primary contexts of cultural transformation. It does not merely transmit knowledge but contributes to the construction of interpretative frameworks through which individuals understand reality and orient their actions.

As highlighted in the literature on sustainability transitions, processes of change require forms of collective learning and social reflexivity that cannot be imposed top-down but must emerge through participatory and inclusive dynamics (Köhler et al., 2019). In this regard, schools can play a strategic role in promoting such dynamics, fostering the development of a culture of sustainability.

Similarly, Stirling (2011) emphasises the importance of recognising the plurality of development pathways and valuing cultural diversity within transition processes. Applied to educational contexts, this perspective implies the need to promote teaching approaches capable of integrating different forms of knowledge, thereby supporting the development of critical and reflective competences.

2. Theoretical and Scientific Background

In recent years, international organisations have emphasised the importance of introducing sustainability education from an early age, not only to transmit scientific knowledge but also to support children's understanding of environmental change and human responsibility (UNESCO, 2019). For young learners, sustainability learning is closely related to how they interpret change over time, understand consequences and remain engaged in situations characterised by uncertainty. From a sociological perspective, these processes contribute to the early construction of environmental awareness and to the development of responsible forms of agency.

At the same time, sustainability education presents both emotional and cognitive challenges. Previous studies have shown that climate-related topics may generate feelings of anxiety, helplessness or confusion, particularly when learning focuses primarily on problems or solutions without adequate conceptual mediation (Buchanan et al., 2021; Baldwin et al., 2023). These challenges

highlight the need for educational approaches that are developmentally appropriate, emotionally responsible and cognitively supportive, capable of sustaining children's engagement while fostering reflective understanding of socio-environmental change.

Digital education has expanded rapidly in recent years and is often presented as a means of improving access to sustainability learning. Digital tools can make invisible processes visible, support interaction with dynamic systems and enable learners to observe change over time (OECD, 2021). As an interdisciplinary field at the intersection of Communication Sciences and Education Sciences, digital education must address the sociocultural, ethical and pedagogical implications underlying the integration of communication technologies into educational systems. According to the Digital Education Action Plan, this requires: (1) improving the quality of the pedagogical use of technologies in teaching and learning processes; and (2) fostering the development of digital competences among teachers and students to respond to contemporary sociocultural transformations (European Commission, 2018), through appropriate digital training (Bulger & Davison, 2018; Hartai, 2014; Hobbs & Tuzel, 2015).

Within a digital educational pathway based on coding, information design and a STEAM approach, learning is conceptualised as the capacity to interpret system behaviour over time, negotiate trade-offs and continue to act within constraints, rather than simply achieving an optimal outcome. From this perspective, the present article proposes a phygital learning environment (Valenti et al., 2012) that avoids reset-based interaction and instead supports learning within a continuously evolving system. The phygital experience integrates physical and digital dimensions within a single educational programme. In this framework, ICT does not replace physical experience but enhances it, expanding opportunities for accessibility, participation and cultural inclusion and supporting socially mediated learning practices.

This paper focuses on the design of an interactive digital strategy for teaching sustainability topics (such as waste reduction and recycling, responsible consumption, green mobility, and energy and water saving) to primary school children. The design protocol, titled *Edumat+*, combines a persistent digital simulation with visual, narrative and physical learning elements to support observation, discussion and collective reflection within a continuously running digital system. The protocol emerges from the integration of multiple scientific fields, including Digital Education, Information Design and the STEAM approach, and is grounded in sociological and pedagogical principles related to social interaction, mediation and collaborative knowledge construction.

Information design encourages children to engage with system behaviour over time and to consider possible actions within realistic constraints. It fulfils four main functions: presenting data within a narrative, comparing information, organising data based on available variables and establishing conceptual correlations that encourage interpretation (Cairo, 2013). In this sense, the discipline aims to provide concise analyses of complex socio-environmental phenomena through appropriate visual representations, without reducing the complexity of the underlying meanings. To achieve this communicative objective effectively, the designer must identify the meaning (or meanings) to be conveyed, establish a visual syntax that reflects this meaning and guide the interpretative behaviour of users (the pragmatics of communication), thereby making the data communicable and readable (Cairo, 2013).

The STEAM approach (Science, Technology, Engineering, Arts and Mathematics), through a multidisciplinary perspective that encompasses creative, artistic and expressive subjects alongside the humanities and interpersonal studies, aims to foster in children (starting from the early years of schooling) problem-setting and problem-solving skills useful for complex learning contexts, while cultivating both conscious and computational thinking (Papert, 1980; Wing, 2006). From a sociocultural perspective, this approach supports collaborative learning practices and the development of soft competences relevant to contemporary knowledge societies.

Digital robots and coding activities are implemented using small visual mats, either pre-defined or designed by teachers and aligned with the themes outlined in the teaching programme. In this context, educational objectives include the cognitive and emotional stimulation associated with the

use of technology for coding activities, primarily related to the development of problem-solving skills as a cross-curricular competence from early childhood, as well as computational thinking linked to the adoption of the STEAM methodology. These activities also support interaction-based learning and shared meaning-making processes.

The objective of the *Edumat+* design protocol is to develop and test a digital–physical prototype integrated into a methodology grounded in social interaction within educational contexts. This approach enables children to explore sustainability topics while maintaining the centrality of educator mediation, as well as the communication and collaboration principles underlying an educational methodology focused on social relationships, dialogical interaction and participatory knowledge construction.

3. Materials and Methods

International education frameworks increasingly recognise sustainability education as a core component of basic education rather than an optional topic. UNESCO emphasises that sustainability education should begin early and support not only knowledge acquisition but also critical thinking and responsible decision-making (UNESCO, 2019). These objectives require teaching approaches aligned with children’s cognitive development, while avoiding excessive simplification of complex socio-environmental processes.

UNESCO (2021) and the EU Green Deal both call for the development of sustainability competences from early education; however, existing programmes often fail to integrate knowledge, emotional engagement and action-oriented learning. Young learners require interactive and hopeful educational experiences that connect understanding with personal agency and socially mediated participation.

Over the past two decades, digital technologies have become increasingly integrated into primary education, particularly in the teaching of science-related topics. However, research has shown that the use of digital tools alone does not guarantee meaningful learning outcomes, especially when complex systems such as climate and environmental processes are involved (Hmelo-Silver & Azevedo, 2006; Assaraf & Orion, 2010).

In sustainability education, young learners often struggle to understand non-linear relationships, delayed effects and cumulative change. These difficulties highlight the need for learning environments that move beyond surface-level interaction and support systems thinking through structured, age-appropriate design. The *Edumat+* protocol responds to these challenges by exploring how interaction design and visual communication can support children in understanding sustainability-related topics as ongoing and constrained processes. Engeness (2021) emphasises that the value of digital learning lies not only in the tool itself but also in how it is pedagogically implemented. She identifies “participatory design and identity reshaping” as key components of digital learning (p. 96), where teachers and students collaboratively design learning tasks. In this perspective, social capital within the classroom and the school becomes a strategic resource for achieving educational objectives. Case studies show that when teachers guide students in shared digital activities, children demonstrate greater engagement with complex topics such as sustainability and environmental change. Digital education, therefore, can support active and socially situated learning practices.

Another important advantage concerns inclusivity. The OECD (2023) highlights that digital ecosystems (Granata, 2015) can adapt to diverse learners’ needs and allow personalised pacing. Gao (2024) further notes that “gamification possesses a great potential to shape human behaviour” (p. 661), explaining that feedback loops in digital environments can satisfy psychological needs such as competence and autonomy. In this way, digitally mediated learning experiences can support young learners in developing a stronger sense of capability, motivation and engagement.

However, digital learning alone is insufficient. Its effectiveness depends on how teachers design and implement educational activities. Engeness (2021) argues that teachers must understand how

digital tasks should be structured to support exploration and reflection. Zainil et al. (2023) found that STEAM programmes can lead to “clear improvements in higher-order thinking” (p. 32), although many activities still rely predominantly on teacher explanation rather than child-led exploration and collaborative inquiry.

Another crucial aspect concerns emotions and motivation. Several studies indicate that knowledge alone is insufficient to promote constructive engagement with sustainability issues. Baldwin et al. (2023) report that many students demonstrate high awareness of sustainability but low levels of hope and agency, arguing that “awareness itself is not a sufficient motivator to cause a change in behaviour” (p. 1600). The authors further observe that many young people experience “low hope and low self-efficacy” when learning about sustainability topics (p. 1605). Similarly, Baker et al. (2021) found that teachers recognised children’s anxiety but “had few tools or training to help them” (p. 694). Many educational activities focus on problems without presenting actionable pathways, leaving children with a sense of helplessness. Ratinen (2021) adds that “knowledge strongly predicts constructive hope” (p. 9), suggesting that well-structured learning environments can support both understanding and a sense of agency.

For example, Buchanan et al. (2021) state that “climate change is a cause of distress and anxiety for children” (p. 17), while Baldwin et al. (2023) describe similar feelings of helplessness, noting that many students doubt their ability to act. This emotional pressure may reduce motivation and make learning experiences less meaningful. Ratinen (2021) shows that positive hope, built on clear and achievable goals, helps students learn more effectively and feel more prepared to take action. From this perspective, hope is not the opposite of fear but a pedagogical resource that enables learners to remain engaged despite uncertainty and complexity.

Baker et al. (2021) report that teachers wish to provide emotional support but often lack appropriate strategies, noting that “the most common challenge by far was adults’ own anxiety” (p. 694). These findings suggest that sustainability education should address emotional dimensions explicitly rather than treating them as secondary. This approach encourages learners to identify what can still be influenced, even when problems cannot be fully resolved. Importantly, a pedagogy of hope does not aim to eliminate negative emotions; instead, it seeks to transform anxiety into reflective engagement by embedding emotional support within learning activities.

For younger learners in primary school, these issues are particularly significant. At this developmental stage, children are highly sensitive to emotional tone and strongly influenced by perceived control and success. Overly catastrophic narratives may increase anxiety, while excessively optimistic narratives risk trivialising the problem. Research therefore suggests the need for learning environments that acknowledge limitations and uncertainty while still offering meaningful opportunities for engagement, participation and the development of agency.

Summarising the literature, many sustainability education approaches focus on transmitting simplified facts or isolated concepts. While this may improve access to information, it does not necessarily support children’s understanding of how systems evolve over time. Consequently, sustainability learning is often framed as information delivery rather than as the development of systemic understanding and interpretative competence.

Secondly, the emotional and ethical dimensions of science learning are frequently simplified or marginalised. However, research indicates that children can engage with complex emotions and ethical questions when appropriate pedagogical support is provided (Buchanan et al., 2021; Baldwin et al., 2023). Avoiding these dimensions may limit opportunities for meaningful engagement, reflective thinking and the development of responsible agency.

Thirdly, classroom integration and teacher agency are often underestimated. Studies and policy reports highlight that digital education tools frequently overlook classroom realities, including limited time, shared devices and teacher workload. When tools lack a clear pedagogical structure, teachers are required to compensate through additional explanation and organisational effort, which may reduce sustainability and continuity of use (OECD, 2021; UNESCO, 2019). This issue is

particularly relevant in primary education, where collective learning practices and teacher mediation play a central role in knowledge construction.

Finally, research on digital learning environments indicates that many interactive tools rely on immediate feedback and reversible actions. While this may reduce frustration, it also encourages short-term trial-and-error strategies that limit learners' engagement with delayed effects and cumulative consequences (Hmelo-Silver & Azevedo, 2006). Such interaction models risk reinforcing procedural engagement rather than supporting systems thinking and long-term reasoning.

On this basis, the study addresses the following research questions:

- How can interaction design and visual communication support young children in understanding sustainability topics as ongoing and constrained processes within digital learning environments?
- How can a learning model informed by constructivism and self-determination theory support children's sense of agency and motivation while operating within systemic constraints?

3.1. The Design Protocol of Sustainability

The *Edumat+* protocol is a digital education framework that integrates knowledge and competences from multiple disciplinary fields, including digital education, information design and STEAM disciplines (particularly coding and robotics) to design and experiment with innovative methodologies for teaching sustainability through interactive learning and active participation of both students and teachers.

The *Edumat+* design protocol constitutes an innovative didactical methodology developed and tested within the European project *Erasmus+ Programme – Key Action 2 – KA220 – Cooperation Partnerships in School Education*, titled *Augmented Educational Mat (2023–2026)*. The project involves 25 primary schools across five European countries (Italy, Spain, Bulgaria, Romania and Portugal) and aims to provide teachers with methodological and pedagogical support for the integration of coding and STEAM approaches in primary education. The main objective was to employ coding and STEAM as innovative tools to support and enhance the teaching of humanities subjects, while activating digital education pathways in primary schools to explore selected topics related to the 2030 Agenda and the humanities.

A second objective of the protocol was to introduce a digital education methodology capable of supporting sustainability learning among children by integrating system exploration, emotional engagement and classroom interaction within a socially mediated learning environment.

The specific objectives were as follows:

- to develop teaching materials tailored to the educational needs of primary school pupils, with particular attention to their psycho-cognitive characteristics, to strengthen teachers' competences in digital literacy and digital education.
- to design an online training pathway introducing primary school teachers to the use of coding for teaching topics related to environmental sustainability and social inclusion in an interactive and participatory manner.
- to complement the bottom-up approach with a top-down scaling strategy aimed at mainstreaming the *Edumat+* methodology and promoting transversal European-level guidelines emerging from the project's methods, outputs and results.

The *Edumat+* project activities focused on fostering collaboration between higher education experts (from university partners) and primary school teachers (from partner schools) in order to promote the integration of STEAM approaches within primary education.

To this end, the following activities were implemented:

- designing, testing and implementing a collection of infographic-based digital education maps intended for primary school classes and focused on themes of environmental sustainability and social inclusion.

- defining, developing and testing a teacher training course on the use of STEAM and coding for teaching humanities subjects in primary education.
- creating a set of best practices and recommendations for school leaders and education policy-makers regarding the adoption of innovative teaching methodologies based on STEAM and coding for humanities education.
- developing and implementing a valorisation and communication strategy aimed at disseminating project outputs and ensuring their long-term sustainability and transferability.

3.2. Main Results

The *Edumat+* project produced three main outputs.

The first output consisted of a *Collection of Digital Infographic Teaching Mats*, including ten Educational Mats that teachers could implement with their students to address different thematic areas. The mats focus on specific topics related to the 2030 Agenda, identified by partner schools to ensure consistency with teachers' needs and classroom practices. In this context, *Edumat+* designed and tested an innovative teaching methodology based on the integration of STEAM, coding and digital education to support targeted didactic interventions.

Drawing on constructivist and sociocultural perspectives, such as those proposed by Piaget (1987) and Vygotskji (2010), children's cognitive development is understood not only as dependent on biological maturation but also as shaped by relationships within social and educational environments. Accordingly, the project outputs were customised for primary school pupils, with particular attention to the psycho-cognitive characteristics of this age group. This approach aimed to strengthen teachers' competences in digital literacy and digital education, in close alignment with the priority of developing key competences.

The main output therefore consisted of a set of ten Digital Mats, accompanied by related booklets and coding instructions. Together, these materials proved effective in supporting knowledge acquisition and facilitating the adoption of STEAM and active learning methodologies in primary school contexts. Through the overall activities, the project contributed to enabling teachers to foster children's soft competences, with the aim of improving learning processes and strengthening digital skills among younger learners, particularly in relation to problem solving, content creation, communication and collaboration.

The collaborative effort of the project partnership resulted in a fully tested and validated collection of digital infographic mats which, by integrating coding elements and storytelling-based methodologies, address issues of environmental sustainability and social inclusion from a multidisciplinary perspective. These resources employ communication strategies aligned with children's experiences and everyday knowledge, thereby supporting meaningful engagement and socially mediated learning.

The second output consisted of an online training course addressed to primary school teachers, providing access to five modules aimed at promoting an in-depth exploration of the STEAM methodology applied also to humanities disciplines. The course was designed and implemented with a specific focus on equipping teachers with the knowledge, skills and competences required in digital literacy and digital education, enabling them to foster children's soft competences and support learning processes through problem solving, content creation, communication and collaboration, in line with the DigComp 2.2 framework (Vuorikari et al., 2022).

The course contents were structured to promote an in-depth understanding of the STEAM methodology applied to humanities subjects, in which coding functions as a pedagogical tool for supporting and enhancing pupils' learning according to their specific needs.

The course provided teachers with knowledge, skills and competences to:

- address and master key concepts related to coding literacy.
- introduce teaching methodologies for the effective classroom implementation of coding.

- apply the potential of coding to explore topics related to environmental sustainability and social inclusion.
- design exemplary learning pathways linked to selected topics of the UN 2030 Agenda, using storytelling integrated with coding activities.

The third output consisted of a set of recommendations and best-practice guidelines, developed both as a publication and as an infographic-based communication tool addressed to decision-makers. These recommendations were elaborated with particular attention to safeguarding the well-being of school-age children in the use of digital devices within STEAM-based learning activities.

This output complemented the bottom-up approach - developed through the identification and review of best practices in digital training and the use of STEAM and coding at primary school level - with a top-down scaling strategy. This strategy focused on the flexible mainstreaming of the *EduMat+* approach through the analysis of national and international regulations and initiatives. The aim was to enable the project to extrapolate and promote transversal guidelines at European level, grounded in the methods, outputs and results produced during the project implementation.

This output contributed to the project's specific objectives by:

- systematising and integrating the use of STEAM and coding in primary school teaching, also from the perspective of European policy frameworks, while considering the training needs and professional conditions of teachers across the different countries involved in the project.
- supporting the institutional recognition of innovative methodologies for teaching humanities subjects and proposing STEAM and coding as pedagogical approaches capable of enhancing disciplinary learning objectives for children.

4. Discussions

The *EduMat+* protocol addressed the needs of primary school teachers by supporting the development of competences required to apply STEAM subjects in early years education. The initiative promoted equitable access to innovation and technology, ensuring that pupils and teachers in primary schools could participate in creative, innovative and collaborative learning activities supported by STEAM-based active learning strategies. As a result, teachers were empowered to personalise learning processes, adapt technological tools and create inclusive learning environments.

With specific reference to the STEAM approach, *EduMat+* demonstrated that the developed methodology can function as an effective mediator for inclusive and engaging learning in primary education. The project produced a set of ten didactic sheets and ten storytelling plots, subsequently implemented in fully operational educational mats addressing themes related to environmental sustainability and social inclusion, which were then used for the creation of infographic mats. More than 100 teachers were directly involved in piloting, assessment and evaluation activities, participating in a qualitative survey of the materials based on shared criteria. The final kits supported teachers in integrating STEAM-based activities into everyday classroom practice, fostering pupils' motivation, curiosity and interest in learning.

To support teachers, school leaders and other educational professionals, the project provided professional development opportunities enabling educators to acquire advanced competences in inclusive STEAM education. These activities offered methodological and technological tools for applying STEAM-based approaches within primary school learning environments.

The methodology applied during the project emphasises two main dimensions:

1. Educational advantages of digital tools

- Data storytelling and data visualisation. These approaches make invisible sustainability processes visible through design choices such as colour, animation and real-time simulation. According to Engeness (2021, p. 104), an "operational scheme of thinking" should be embedded in digital design so that learners can visualise learning steps. The literature reviewed highlights both progress and persistent limitations in digital sustainability education. Research on digital pedagogy and motivation shows that meaningful learning depends not only on technological

affordances but also on how teachers structure learning experiences and how learners perceive autonomy, competence and relatedness (Engeness, 2021; Gao, 2024). Studies on systems thinking demonstrate that climate concepts can be introduced through structured modelling and diagnostic approaches, while also revealing challenges in helping learners understand dynamic behaviour and long-term change (Zainil et al., 2023; Szozda et al., 2023).

- Interactivity through robots and coding. These tools allow children to manipulate simple variables and observe visible system responses over time. Learners construct concepts progressively through action, feedback and reflection. From a constructivist perspective, as highlighted by Piaget and Vygotskji, children understand abstract ideas more effectively when they can manipulate objects, test variables and observe outcomes. Through robotics, learners move from physical action to deeper conceptual understanding. As Engeness (2021, p. 101) notes, this shift occurs through “materialized action – communicated thinking – dialogical thinking – acting mentally”.
- Immediate feedback within coding activities. This feature enables the visualisation of delayed consequences of learners’ actions over time, supporting reflection on cumulative effects and system behaviour.
- The STEAM approach as a methodological framework. Zainil et al. (2023, p. 32) report that students in STEAM-based digital classrooms developed stronger critical thinking, creativity and communication skills than peers in traditional settings. Digital STEAM tasks encourage students to “think critically and creatively, cooperate, respect one another and communicate the solution”. In methodological terms, STEAM provides an appropriate framework for making complex system behaviour accessible to children. For younger learners, STEAM offers multiple entry points to abstract concepts through visual, tactile and narrative learning modes (UNESCO, 2019, p. 10). Within this framework, the arts function not as aesthetic additions but as cognitive scaffolds that externalise abstract relationships and support discussion.
- Emotional transformation through visual storytelling. Integrative visual narratives, combined with call-to-action activities and small achievable goals, help transform anxiety into constructive hope. According to Self-Determination Theory (SDT) (Deci & Ryan, 2017), intrinsic motivation is a stronger predictor of performance quality, whereas extrinsic incentives primarily predict performance quantity and are more effective for simple algorithmic tasks (pp. 16–17). Human motivation is shaped by the satisfaction of three basic psychological needs: autonomy, competence and relatedness. When these needs are supported, learners are more likely to internalise goals and engage in self-directed learning. Autonomy refers to experiencing actions as meaningful and self-endorsed; competence refers to feeling effective when facing challenges; relatedness refers to feeling connected and supported by others. SDT emphasises that these needs operate in an integrated manner rather than independently.
- Teacher usability. Structured lesson guides and prompts for emotional dialogue were designed to support teachers in their mediation role within classroom interaction.

2. Principles of the educational process

- Teacher–student relationships. From a constructivist perspective, learning is inherently social. Hmelo-Silver and Azevedo (2006) argue that “discovery alone is not sufficient” for learning in complex domains and that learners require structured support to interpret observations (p. 55). Without scaffolding, students may engage in activity without developing explanatory understanding, focusing on surface-level manipulation rather than system behaviour over time. This issue is particularly relevant in complex systems learning, where causal relations are non-linear, delayed and often counterintuitive.
- Immediate teacher feedback. Ongoing pedagogical mediation supports interpretation of results and promotes reflective understanding of learning activities.
- Practical experience through manipulation of objects. Hands-on interaction reduces cognitive overload and supports engagement. Cognitive overload may lead to frustration or disengagement, while unmanaged anxiety can undermine motivation. Conversely, experiences

of understanding and agency can support emotional regulation and sustained engagement. Despite this interdependence, few studies propose learning models that explicitly connect thinking, feeling and acting within a developmentally appropriate framework.

- Cooperative learning in small groups. Collaborative activities promote shared problem solving and collective knowledge construction. In groups, students share hypotheses and negotiate solutions during learning tasks, fostering reflective reasoning improving collaboration and dialogue.
- Group brainstorming and shared decision-making. These activities allow students to share emotions, opinions and interpretations. According to Engeness (2021, p. 104), learners initially test ideas individually and then compare outcomes. The transition from “communicated thinking” to “dialogical thinking” helps them clarify and refine their ideas, while shared discussion encourages questioning of assumptions and consideration of multiple perspectives.

5. Conclusions

Through the *Edumat+* protocol, a new design protocol for digital education was developed and piloted in primary schools across five European countries (Italy, Spain, Portugal, Bulgaria and Romania). The protocol involved the use of communicative artefacts, both digital and non-digital, in school education from a Digital Education perspective, through the design of infographic mats to be used for educational purposes in the implementation of curricular activities within primary education. These mats focused on the themes of the UN 2030 Agenda, explored across different primary school subjects through an interdisciplinary approach and through the involvement of curricular teaching, in line with the expected learning outcomes for pupils attending primary school.

The project adopted STEAM-based educational methodologies aimed at implementing coding activities with the support of a kit of physical robots (specifically Sphero Bolt), designed for the age group targeted by the project. The use of robots was further integrated with coding support services, so that the virtual applications used to programme the robots could be manipulated via smartphones, tablets or personal computers.

Each *Edumat+* educational kit was designed to be tested within an educational pathway implemented in primary schools, involving multiple subjects from an interdisciplinary perspective. The pathway was structured into four sessions, each including a micro-design of teaching and learning activities. These activities were organised into progressive learning pathways in which students’ cognitive engagement gradually increased, moving from a basic level in the first session, characterised by educator-mediated and guided activities, to more advanced levels where students progressively developed greater autonomy in carrying out tasks and solving problems.

Within this protocol, school social capital plays a strategic and central role, understood as the set of relational, normative and trust-based resources emerging from interactions among students, teachers, families and institutions to foster learning processes, inclusion and students’ educational success. In the educational field, social capital is therefore a collective resource constructed within school social networks, enabling the circulation of information, support and shared expectations (Coleman, 1988; Bourdieu, 1986). In this sense, the implementation of the project emphasised and encouraged peer interaction and teacher - student relationships during activities, communication and collaboration in problem-solving, the sharing of ideas and brainstorming on possible strategies.

In summary, the educational potential of the programme proved to be multifaceted:

- Drawing on the ISOTYPE approach developed by Neurath (1936), the adoption of a visual language through visual storytelling, aimed at “explaining through images”, highlighted the democratising power of visual design, namely the possibility of transferring knowledge clearly to a wide range of learners with different competences and levels of learning. Visual (infographic) language is easily recognisable and interpretable even by those who do not possess adequate linguistic codes (for example, immigrant students), by learners with specific learning difficulties (dyslexia, dyscalculia, etc.), and by students who display different learning and

expressive rhythms shaped by diverse sociocultural family contexts. The narrative strategy itself also supports the memorisation and recall of complex disciplinary concepts.

- The adoption of multiple representational languages, including the tactile and sensory affordances of the robot, enabled students to learn in a multisensory way. The multimedia dimension of digital environments, together with their multisensory engagement, fosters diversification of learning processes and accommodates children's different learning paces. According to Munari (1981), however, all sensory and multimedia materials designed for educational purposes must satisfy and respect several shared principles to be effective for learning:
 - they should allow children free choice and self-correction.
 - they should respect individual learning times.
 - they should enable spontaneous repetition.
 - they should facilitate sensory exploration and the use of hands.
 - they should make the abstract concrete and support concentration.
 - they should create tasks with a precise objective and a clear endpoint.
 - they should not be aimed at the direct acquisition of technical skills.
 - they should be aesthetically appealing and engaging for the child.
- Learning by doing, or experiential learning through manipulation and the use of robots, also represents a valid and central principle in this digital education project. Tactile experience and active engagement, together with processes of behavioural imitation, form the basis of children's learning processes, as also argued by Jean Piaget. In this sense, the use of technologies that involve interaction with digital objects and the manipulation of physical artefacts (e.g. in robotics or coding activities) fully embodies this Montessori-inspired principle. In this way, students "learn how to learn" within a rich environment and consequently how to solve related problems in real-world contexts (Dunleavy & Dede, 2014).
- Attention in the project was devoted to fostering children's autonomy, understood as supporting their sense of freedom to act and learn independently. This involves several aspects, including:
 - teaching children to make choices and solve problems independently (Montessori, 2017).
 - Respecting rules for sharing a physical, social and digital space.
 - Maintaining order: all objects used by children during educational play should be returned to their original place.
 - Ensuring social relationships during the implementation of the project was also essential. Such relationships contribute to children's social and emotional well-being during the learning process and should be caring, calm, stimulating and at the same time minimally noisy. Especially within a Digital Education perspective, it is important to preserve dialogue, exchange and collaboration during device use. Relationships should be non-competitive and inclusive, encouraging children to take care of the environment and interact with others in a respectful and collaborative way.

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