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Networked learning environments: educational infrastructures, conditional affordances, and digital inequalities.

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Abstract: Networked digital environments have structurally transformed contemporary education, redefining teaching, learning, and collaboration. This paper conceptualizes these environments as educational infrastructures (Star & Ruhleder, 1996), that is, sociotechnical systems that structure pedagogical relationships, distribution of authority, and patterns of participation. Drawing on sociocultural learning theory (Vygotsky, 1978), the critique of educational technology (Selwyn, 2014, 2024), and the conceptual framework of conditional affordances (Dohn, 2023; Hutchby, 2001), the study examines how digital sociality mediates communication, collaboration, multimodal engagement, and pedagogical roles. This theoretical framework is complemented by a mixed-methods empirical study conducted in a fifth-grade elementary school class (n = 28), which spanned eight weeks of intervention using a collaborative platform.
The results show significant increases in sense of community (SSCS: $\Delta = +0.63$; $p < .001$) and digital self-efficacy (SADSP: $d = 0.52–0.71$), but reveal persistent inequalities related to the third level of the digital divide (Van Deursen & Helsper, 2015) and the early emergence of ethical tensions related to visibility, performative pressure, and presence bleed (Gregg, 2013). The study offers guiding principles for a pedagogically sound, equitable, and ethically informed integration of online environments into educational practice.

Keywords: Online learning environments; Educational infrastructure; Primary school; Inclusive teaching.

1. Introduction and Theoretical Framework

The COVID-19 pandemic has marked the definitive shift from technology as a tool to technology as the basic infrastructure of education (Decuypere et al., 2021). Hybrid and digitally mediated forms of learning are now permanent features of many educational systems, albeit unevenly distributed across institutional contexts and resource levels (Selwyn, 2024; Trinchero, 2025). Understanding these environments requires moving beyond instrumental perspectives that treat technologies as neutral vehicles of pedagogical intent (Selwyn, 2014) to adopt an infrastructural mindset (Star & Ruhleder, 1996): digital networks do not simply support learning, they structure its conditions, distributing authority, visibility, and opportunities for participation.

The sociocultural perspective (Vygotsky, 1978; Rogoff, 1990) provides the second theoretical pillar: learning is fundamentally social and situated, emerging through interaction in cultural and relational contexts that online environments extend across space and time. The affordances of these systems—temporal extension, multimodal

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participation, collaborative knowledge construction—are not, however, intrinsic properties of technology, but relational configurations that depend on the student's social capital, pedagogical design, and institutional logics (Dohn, 2023; Hutchby, 2001). The same platform can enable deep engagement in one context and produce superficial interaction in another. These opportunities are accompanied by significant structural constraints: the datafication of the educational experience (Williamson et al., 2020; Raffaghelli, 2023), the risk of a third level of the digital divide, no longer linked to access but to the actual benefits obtained from use (Van Deursen & Helsper, 2015), the dissolution of the boundaries between academic and personal life (Gregg, 2013), and the need for ethical governance of spaces of visibility (Pangrazio & Selwyn, 2019). These tensions, widely studied in secondary schools and universities, remain underrepresented in the literature on primary schools, despite DigComp 2.2 (Vuorikari et al., 2022) emphasizing the centrality of critical digital literacy from the earliest stages.

This paper addresses this gap through an embedded mixed methods study (Creswell & Plano Clark, 2018) conducted in a fifth-grade elementary school class, with the aim of: a) empirically exploring how a structured collaborative digital environment changes participation patterns and pedagogical roles; b) verifying whether the intervention amplifies or reduces pre-existing inequalities; c) identifying emerging ethical tensions in the daily use of collaborative platforms with 10-11 year-old students.

2. Materials and Methods

The adopted design is an embedded mixed methods type with a prevalence of qualitative (Creswell & Plano Clark, 2018), implemented through collaborative action research (Kemmis et al., 2014) that involved the principal researcher, the principal teacher, and the school principal in an iterative process of co-planning, implementation, observation, and reflection. The research involved a fifth-grade class of a state primary school in a medium-sized municipality in southern Italy (Apulia, province of Bari): 28 students (15 females, 13 males; ages 10-11), with significant sociocultural heterogeneity (21.4% migrant background; 14.3% with certification L. 104/1992 or L. 170/2010). The principal teacher (18 years of seniority, trained in digital teaching PON) actively participated in the co-planning. Written informed consent from parents was obtained for all 28 students; Approval by the Institutional Ethics Committee; data processed anonymously (GDPR 2016/679).

The intervention took place over eight weeks (January - February 2026), for a total of 32 hours integrated into the regular curriculum timetable, on the Google Workspace for Education platform (Classroom, Documents, Presentations), already adopted by the school. Four interdisciplinary Learning Units (history, Italian, science, civics) were developed according to the principles of Universal Design for Learning (Rose & Meyer, 2002) and Collaborative Knowledge Building (Scardamalia & Bereiter, 2006), divided into three phases: a) asynchronous activation in Classroom with multimodal materials; b) synchronous co-construction in small groups on a shared document; c) presentation and peer review in plenary.

Phase 1 (weeks 1–2) included the baseline survey and technical training for students on the platform. Phase 3 (weeks 7–8) included the re-administration of the tools, focus groups, and an interview with the teacher.

The structured participant observation consisted of 16 sessions, each lasting 90 minutes and conducted twice a week. The observation used a grid based on the Community of Inquiry Framework (Garrison et al., 2001), capturing cognitive, teacher, and social presence.

To analyze the digital logs, the export and analysis of access and interactions of all 28 students was performed using elementary Social Network Analysis (SNA).

The questionnaires used both pre- and post-intervention were:

1) Student Social Connectedness Scale — SSCS (Rovai, 2002), 20 Likert items ranging from 1 to 5;

2) Digital Self-Efficacy Scale for Primary Schools — SADSP, developed specifically for three dimensions (technical competence, online collaboration, multimodal communication; Cronbach's α pre = 0.81; post = 0.83);

3) Collaborative Learning Motivation Inventory — IMAC-P (adapted from Järvelä et al., 2010).

A focus group was also conducted, divided into three sessions, each lasting 30 minutes. Subgroups were created based on access frequency (high/medium/low). The participants were transcribed verbatim and analyzed using reflective thematic analysis (Braun & Clarke, 2021).

A semi-structured interview with the teacher was also conducted, lasting 60 minutes and analyzed using categorical content analysis (Mayring, 2014).

3. Results

3.1. Partecipation Pattern (RQ1)

Analysis of digital logs revealed an average participation of 4.7 weekly accesses per student (SD = 1.8), with a statistically significant increase from week 1 to week 4 ($t(27) = 3.42$; $p < .01$; $d = 0.64$).

Table 1. Distribution of students by average weekly access frequency (n = 28)

Frequency band	Students N.	%
≥ 6 accesses/week (High)	9	32,1
3–5 accesses/week (Average)	14	50,0
< 3 accesses/week (Low)	5	17,9

The SNA analysis of the 1,247 comments identified three stable interaction clusters (network density = 0.38), above the functional threshold for CSCL (Kreijns et al., 2003). However, high degree centrality was recorded for four students, indicating information brokering dynamics that require pedagogical monitoring to prevent exclusions. The correlation between access frequency and intrinsic motivation (IMAC-P) was positive and significant ($r = 0.62$; $p < 0.001$), confirming the role of situated motivation in CSCL contexts (Järvelä et al., 2010).

3.2. Teaching roles transformations (RQ2)

The qualitative analysis identified four macro-categories of role transformation:

a) from provider to orchestrator: in 68% of sessions, the teacher primarily performed coordination and structured scaffolding functions, shifting action from a frontal position to circulation between groups;

b) intensification of invisible digital work: in the first three weeks, there was an overload related to technical management and redesigning deliverables, consistent with Selwyn et al. (2018);

c) reactive critical curation: in 7/16 sessions, the teacher introduced unplanned additional resources in response to emerging questions (Mihailidis & Cohen, 2013);

d) ethical moderation of visibility spaces: on three documented occasions, it was necessary to mediate relational conflicts that emerged on the platform, confirming the centrality of pedagogical judgment in digital governance (Biesta, 2023; Salmon, 2011).

3.3 Inequalities in participation (RQ3)

Pre-post comparisons (Table 2) show statistically significant improvements on all instruments (Wilcoxon test, $p < 0.05$; $0.52 \leq d \leq 0.71$). However, the 5 low-attendance students do not show significant increases on the SADSP ($d = 0.19$; $p = 0.24$), confirming the third level of the digital divide (Van Deursen & Helsper, 2015): guaranteed access does not automatically produce equitably distributed benefits.

Table 2. Pre-post comparison on SSCS, SADSP, and IMAC-P - entire group (n = 28)

Tool	Pre M	Pre SD	Post M	Post SD
SSCS	3,21	0,71	3,84	0,58
SADP – Technical Comp.	2,89	0,83	3,67	0,62
SADSP – Online collaboration	2,74	0,91	3,59	0,71
SADSP – Multimodal Comm.	2,61	0,88	3,42	0,79
IMAC - P	3,10	0,76	3,72	0,61

Students with L. 104/L. 170 certification showed mixed results: two ranked among the high-frequency participants, benefiting from multimodal expression as an alternative to written text (consistent with UDL principles; Rose & Meyer, 2002); two others required unplanned individual differentiation, highlighting the limitations of standardized digital designs in inclusive contexts.

3.4. Ethical and managerial tensions (RQ4)

The reflexive thematic analysis of the focus group corpus (~14,600 words) yielded four themes:

1) Visibility and performance pressure: 11/28 students (39.3%) expressed discomfort with the publicity of their contributions, developing self-censorship strategies that depleted the cognitive quality of interactions (Raffaghelli, 2023; Selwyn & Facer, 2014).

2) Porosity of temporal boundaries: 7/28 (25.0%) accessed the platform in the evenings or on weekends on their own initiative, indicating an early emergence of presence bleed (Gregg, 2013) already in the 10-11 age group.

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3) Increased sense of community: 16/28 (57.1%) attribute the digital experience to a positive effect on group belonging, consistent with the increase in SSCS (Δ = +0.63).

4) Perceived disparity in skills: 9/28 (32.1%) recognize internal differences that generate delegation dynamics, reducing the cognitive exposure of less experienced students, although in some cases spontaneous forms of peer tutoring emerge.

4. Discussion

The results empirically confirm and enrich the theoretical framework adopted, offering unprecedented evidence for the primary school context.

The introduction of collaborative digital environments does not automatically lead to inclusive and equitable participation. The persistence of significant differences in low-attendance subgroups recalls the agency paradox (Castañeda et al., 2025): digital autonomy is not a prerequisite for students but an educational objective to be built through systematic and differentiated scaffolding.

Furthermore, the transformations in the role of teachers confirm the need to redefine the professional profile of teachers in digital ecosystems (Laurillard, 2023; Rivoltella, 2025). The shift from provider to orchestrator is not without costs: the increased workload and the ethical management of visibility spaces require institutional recognition of invisible digital work (Selwyn et al., 2018), which is still ignored by school staff evaluation systems.

Another factor is the early emergence of presence bleed among 10- and 11-year-old students. This represents an empirically unprecedented finding that highlights the urgent need for a pedagogy of attention and digital well-being structured from the primary school level (Stiegler, 2024; Newport, 2023), as well as explicit institutional norms regarding the right to disconnect.

Finally, the self-induced performative pressure of students in shared digital spaces, in the absence of explicit algorithmic monitoring, confirms the implicit datafication of assessment (Raffaghelli, 2023): students internalize the logic of continuous control inherent in the platforms, developing defensive strategies that stifle cognitive exploration. Designing digital spaces that valorize error and process remains one of the most pressing challenges for inclusive digital education.

From a methodological perspective, the embedded mixed methods approach enabled effective triangulation between log data, standardized measurements, and qualitative analysis, producing a more robust interpretative framework than could be achieved with single-method approaches. Collaborative action research enhanced the teacher's professional knowledge as an epistemic resource, consistent with Biesta's (2023) perspective on pedagogical judgment as an irreplaceable skill in the governance of digital environments.

5. Conclusions

This study empirically demonstrated that online learning environments function as educational infrastructures already in primary school: they structure participation patterns, distribute pedagogical authority, and redefine the boundaries between school and personal time. Quantitative results demonstrate significant improvements in the sense of community and digital self-efficacy; qualitative results reveal ethical tensions that require structural, not technical, attention.

In summary, four guiding principles for informed integration emerge from the theoretical analysis and empirical data:

1) Prioritize equity: design digital environments with explicit attention to student variability, adopting UDL principles and differentiated support;

2) Recognition of teaching work: institutions must contractualize invisible digital work and ensure adequate training and technical support;

3) Pedagogy of digital well-being: introduce explicit rules for disconnection, attention training, and the right to make mistakes in shared spaces from primary school;

4) Critical data literacy: shifting the focus from behavioral digital citizenship to understanding algorithmic logic and data flows (Pangrazio & Selwyn, 2019; Raffaghelli, 2023), building the awareness that the EU AI Act (2024) now makes urgent, even for basic education cycles.

The study has limitations related to its unit-case design (single class, single context) and the duration of the intervention. Future research could extend the multi-site design, integrate longitudinal learning analytics, and explore the impact of intelligent conversational agents on CSCL processes at the primary level (Lund & Hauge, 2024), an area of research that the EU AI Act (2024) classifies as high-risk, requiring rigorous ethical governance.

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