

Beyond prohibition: smart environments and co-evolutionary learning in secondary schools

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Abstract: In recent years, the debate surrounding the use of digital devices in schools has become polarised. There are prohibition policies which aim to restrict the presence of smartphones and tablets in classrooms, but there is also a growing awareness that digital competence is an essential aspect of modern citizenship. Taking as its epistemological framework the perspectives of extended cognition (Clark & Chalmers, 1998) and co-evolutionary learning (Rivoltella, 2017), this article offers a theoretical and experimental reflection on this tension. Through a qualitative-quantitative experimental study involving two groups of lower secondary school students, we investigated the impact of incorporating a smart learning environment based on digital devices, environmental sensors, and embodied activities on attentional functions, critical thinking, and school motivation. The results showed significant improvements in the experimental group compared to the control group. This suggests that pedagogically oriented technology use can support embodied and distributed cognitive processes. This is in contrast to normative narratives that interpret digital technology solely as a source of distraction. The article discusses the implications of these findings for the development of a pedagogy of intelligent environments that can rethink the educational space as a cognitive ecosystem in which the body, mind, environment and technology co-evolve synergistically.

Keywords: digital devices, smartphones, tablets, teaching, embodied, school

1. Introduction

The use of electronic devices in the classroom has become a central and controversial issue in contemporary educational debates. On the one hand, a growing number of regulations encourage or impose limits — and, in some cases, outright bans — on the use of smartphones, tablets, smartwatches, and other digital devices during lessons. These regulations are often based on the implicit idea that the mind can and should be isolated from technological distractions, treating cognition as an internal, autonomous process vulnerable to external influences. However, the importance of digital education — not merely as a habit, but as a critical and cultural skill — leads us to question the epistemological, pedagogical, and political implications of such restrictions.

In other words, banning technology in the classroom is not only a disciplinary choice,



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but also an act of epistemic exclusion which confines the technological dimension outside the sphere of knowledge. If, as today's interdisciplinary research suggests, cognition is an emergent process constructed through the interaction of body, tools, and environment, then the question 'How can learning still be considered as merely the transmission of information?' (raised in the call 'Pedagogies of Co-evolution, 2025') is not rhetorical; it is an essential theoretical juncture. To what extent does teaching that excludes digital technology implicitly reaffirm models of the isolated mind that have been superseded by contemporary research in the philosophy of mind, cognitive science, pedagogy, and media studies?

In recent decades, there has been a growing theoretical convergence towards models that reject the idea that the mind is confined to the brain in various ways. Theories of embodied, embedded, extended and enacted cognition — known as 4E cognition — argue that the mind is an open system that emerges in interaction with the body, the environment and tools, and is not an “internal archive” or an isolated abstract processor. These theories are promoted by philosophers such as Shaun Gallagher, author of *Reflections on “Cognitive Institutions”* and the *Body-Schema/Body-Image Distinction*.

From this perspective, technical artefacts are active partners in the construction of thought, not mere external accessories. Clark and Chalmers (1998) theorised the famous extended mind thesis, according to which external devices such as notepads, calculators and software can become an integral part of the cognitive system provided there is immediate accessibility and automatic use, and a functional symbiosis with the agent (Clark and Chalmers, 1998; *PhilPapers*). (*PhilPapers*).

However, the extended mind alone is not enough; embodied cognition must also be mobilised to emphasise the constitutive role of the body, movement, sensory perception and motor action in knowledge (Berthoz, 2009; Sibilio, 2014). According to this view, learning is never disembodied: what I perceive with my body, how I move, the spatial arrangement in which I act and the posture I adopt all participate in cognitive processing.

However, the body and tools alone are insufficient; the environment also plays a role. The embedded and enacted perspectives assert that cognitive processes unfold within contexts offering constraints, affordances, sensory resources and structural limitations. In other words, the mind does not extend into the world; rather, it emerges from the continuous intertwining of agent and environment. This is the situated cognition (or strong situated cognition) point of view.

These models are supplemented by the concept of the distributed mind (Hutchins, 1995), which posits that cognition not only extends into tools, but is also distributed across multiple levels and agents (human, social and technical). Memory, attention and coordination frequently occur within socio-technical networks rather than in isolation. Finally, Rivoltella (2017) expands upon the concept of co-evolutionary learning, whereby minds, tools and environments interact and transform one another. The use of technology shapes the mind, which subsequently influences the use of technology.

In recent years, this paradigm has been further enriched by critical perspectives questioning how artificial intelligence and digital environments extend (or risk replacing) human cognition. Rivera-Novoa et al. (2025) reflect on generative AI through the lens of extended cognition, warning that such systems could turn students into passive subjects unless they are redesigned to complement rather than replace cog-

nitive processes. Furthermore, the concept of hybrid cognition or hybrid intelligence (Cukurova, 2024) suggests that AI should be considered not merely as a tool, but as a cognitive co-agent integrated into the human-technological learning network. (Arxiv). In summary, the current theoretical landscape invites us to reconsider the mind, learning, and the educational environment, not in terms of internal versus external, but in terms of co-construction and co-transformation. Cognition is not confined to the brain; rather, it exists within the relationship between the brain, the body, tools, and the environment.

Despite this theoretical ferment, educational policies often lag behind emerging visions. In Italy, for example, ministerial guidelines on digital technologies in schools oscillate between cautious regulation and prohibition; the device is viewed with suspicion as an invader whose physical presence is perceived as a potential distraction. This attitude reflects a mindset that is still strongly influenced by the 'myth of the mind'.

In light of the assertion made during the conference call that cognition is an emerging process and linear information transmission is in crisis, the tension surrounding the fact that schools continue to favour teaching models that neutralise the technological element is particularly acute. To what extent are these devices treated as enemies to be banished rather than cognitive extensions to be cultivated? In this sense, the ban is not innocuous; it signals an understanding of knowledge that fails to recognise its hybrid, multiplied and interconnected nature.

The contradiction between official discourse extolling digital education and practical restrictions on device use is particularly striking. It not only limits the possibility of learning with technology, but also implicitly teaches students to separate the cognitive world — the 'real' world — from digital spaces, which remain secret or forbidden. Thus, the ban is not merely a disciplinary measure, but also a cultural act, preventing the development of a radically extended pedagogy of the human-environment-technology network.

In recent years, educational research has started to combine 4E models with practical applications. A recent meta-analysis published in the *Interactive Learning Environments* journal found that technology-based embodied learning (TBEL) had a moderate and significant impact on cognitive and non-cognitive outcomes, with variations related to the extent of bodily involvement and the length of the intervention.

A more recent narrative review (2024) identifies six research directions that could clarify how embodied cognition promotes learning, including physical activity, generative learning, offloaded cognition and motor observation. It also suggests that integrating movement and learning is essential for educational effectiveness, not just an embellishment. In the context of immersive technologies, a recent study on an AR (augmented reality) game conducted with primary school students highlighted how physical interaction with the environment, body use and social interaction could increase motivation, engagement and learning, thus demonstrating the potential of embodied learning.

Other studies, for example in linguistics, demonstrate that language learning benefits from embodied approaches in which gesture, movement, and physical context contribute to the construction of meaning (review up to 2020).

Finally, experiments combining smart environments with sensory devices are emerging. Modulations of light, sound, and environmental feedback linked to cogni-

tive tasks have shown potential for improving concentration and cognitive performance quality (although these studies are still exploratory). In parallel, the rise of generative AI raises questions about the relationship with extended cognition. Rivera-Novoa (2025) warns of the risk of AI becoming substitutive rather than complementary, but also outlines strategies for incorporating it into active cognitive processes.

This evidence suggests that intelligent environments can be experimented with that are not merely 'add-on' technology, but components of a dynamic cognitive ecosystem in which the device, body, space and environmental ecosystem respond synchronously to learning needs.

In light of this theoretical and empirical framework, the present study adopts a novel approach: rather than asking how to control the use of technology in the classroom, it considers how to transform the use of devices into a cognitive resource in real school contexts. Specifically, it explores whether an intelligent learning environment designed to integrate the body, technology and space more effectively can enhance attention span, critical thinking and academic motivation compared to traditional teaching methods that exclude or limit devices.

From this perspective, the device is never neutral; it can hinder or help, depending on how it is integrated into the educational context. The expected contribution is two-fold: First, it will produce empirical data through a qualitative-quantitative experimental approach with comparison groups. This data will shed light on the feasibility and effectiveness of smart environments in real school contexts. Second, it will translate this data into pedagogical guidelines consistent with an extended pedagogy. This pedagogy will overcome the prohibition/*laissez-faire* antinomy and pave the way for a school capable of critically engaging with the cognitive hybridisation between humans, technology, and the environment.

Thus, the introduction of technology into the classroom will not be a marginal addition, but rather the creation of a co-evolutionary cognitive network. Rather than being removed, the device should be embraced as an educational tool, not as an intruder to be managed, but as a co-intentional agent of thought. While prohibition signals the continuing relevance of the isolationist paradigm, educational experimentation constitutes a practical and theoretical argument against it. This study is grounded in the idea of placing technology at the centre — not as an end in itself, but as a means of cognitive embodiment.

2. Methods

2.1 Participants

The study was conducted at a lower secondary school in a medium-sized municipality in the Campania region. The municipality was characterised by an average socio-economic context and a rate of domestic digitisation in line with the national average. The school was selected based on its availability of flexible teaching spaces and its teaching staff's previous experience in educational innovation projects. This made it a suitable environment for conducting a controlled experiment on the use of technology in the classroom.

The sample consisted of 60 students, aged between 12 and 13 (mean = 12.5, standard deviation = 0.4), who were enrolled in two parallel classes in the same year group. To reduce bias related to pre-existing variables (performance level, gender, academic

motivation and familiarity with digital technology), the students were randomly assigned to two groups of equal size ($n = 30$ each).

The experimental group participated in a six-week educational programme carried out in a specially equipped smart classroom with environmental sensors (brightness, temperature and noise), an interactive multimedia whiteboard, individual tablets and a system for dynamically adapting lighting and acoustic conditions based on attention levels detected by non-invasive behavioural monitoring software. Activities integrated the use of digital devices as cognitive tools to support subject learning, particularly in science and technology.

The control group followed the same curriculum and timetable as the experimental group, but in a traditional manner without digital devices or environmental sensors. The same teacher was used for both groups to ensure methodological comparability and control for the possible teacher effect.

2.2. Inclusion Criteria

The study included students who:

1. were regularly enrolled in school at the start of the trial;
2. attended classes regularly (minimum attendance of 75% of the scheduled period);
3. had obtained informed consent from their parents or legal guardians to participate in the research;
4. did not have sensory or cognitive disabilities that would significantly interfere with participation in technological activities or with the measurement of attention variables.

The decision to limit the age of participants to 12-13 years was motivated by the fact that pre-adolescence is a period of particular cognitive plasticity and transition in learning modes, as well as being an age at which the independent use of technology becomes socially and educationally relevant.

2.3. Exclusion Criteria

Students were excluded if they:

1. had not completed the entire experimental programme due to prolonged absences or transfers
2. had a certified diagnosis of Specific Learning Disorders (SLD) or other special educational needs that required significant adjustments to the experimental setting;
3. used personal digital devices during control group lessons, in contrast to the research protocol;
4. exhibited levels of behavioural opposition that compromised regular participation.

Applying these criteria ensured the homogeneity of the sample and the internal validity of the study, preventing individual or contextual variables from interfering with the measurement of the effects of the independent variable (type of learning environment).

The entire protocol was conducted in accordance with the ethical standards set out in the Ethics Committee guidelines of the referent university, in accordance with the

Declaration of Helsinki and the European Data Protection Regulation (GDPR 2016/679). All participants and their families were given clear information about the study's objectives, the nature of the activities, and the confidentiality of the collected data. No biometric tracking systems or identifiable images were used; behavioural observations were made anonymously and in aggregate.

A preliminary calculation of statistical power determined the total number of students to be 60 (power = 0.80; $\alpha = 0.05$; expected average effect = 0.60). This suggested that a minimum of 25 subjects per group would be sufficient to detect significant differences in attention and motivation scores between the experimental and control conditions. The sample size was then increased to 30 participants per group to compensate for potential exclusions or absences.

The intervention was part of a broader methodological innovation project promoted by the institute, in collaboration with a university laboratory of experimental pedagogy. The school, already engaged in digital civic education and inclusion activities, showed a high willingness to experiment with teaching approaches based on the relationship between body, technology and environment. This made it possible to place the research in an authentic context, while maintaining the experimental rigour required for the empirical evaluation of the initial hypotheses.

2.4 Activities

Experimental Group

The smart environment used for the experiment was designed to be an adaptive and responsive learning space that would promote dynamic interaction between students, technologies, and the physical context. Rather than simply introducing digital devices into the classroom, the idea was to create a cognitive ecosystem in which the physical dimension, technological mediation and spatial configuration would cooperate in constructing knowledge.

In line with the models proposed by Rivoltella and Rossi (2019) on the 'media ecology of teaching', the laboratory was organised according to a principle of modularity and environmental plasticity, where the environment becomes an active agent in the educational process. The spatial layout included flexible learning islands that could be easily reconfigured according to the type of activity — such as dialogic lessons, group work or individual exploration — as well as a series of integrated technological nodes that responded in real time to measurable environmental parameters.

The space was equipped with:

- Individual tablets (one per student) with controlled access to digital educational resources, subject-specific applications and synchronous collaboration tools (shared pads, visual brainstorming platforms). The tablets were not used merely for content consumption, but for the active construction of knowledge, in line with constructivist perspectives (Jonassen, 1999) and mediation pedagogy (Calvani, 2020).
- Environmental sensors for brightness, sound and movement, connected to a visual and acoustic feedback system that allowed the conditions of the space to be adjusted adaptively. The light intensity, for example, varied according to the levels of attention observed: during individual concentration activities, the lights took on cool and stable tones, while during collaborative work, warmer and more dynamic tones were favoured. This approach stems from research on multisensory environments for

learning (Barrett et al., 2015; Beery et al., 2021), which highlights the impact of spatial variables on motivation and cognitive engagement.

- Mobile ergonomic chairs and modular tables, designed to encourage active posture and role rotation within work groups, in line with the literature on embodied learning (Shapiro & Stolz, 2019), according to which the body acts as a cognitive mediator.
- Sound-absorbing panels and acoustic control devices that ensured an optimal sound environment, reducing the cognitive load associated with environmental distractions (Klatte et al., 2017).

This space was designed based on the principles of situated pedagogy (Lave & Wenger, 1991), which views learning as participation in social and material contexts, and the concept of 'smart learning environments' (Baker et al., 2020), where adaptive technologies and environmental design come together to encourage integrated cognitive and socio-emotional processes.

The intervention lasted six weeks in total, during which the experimental group of students took part in three weekly 90-minute sessions. These activities were designed to strike a balance between independent exploration, collaboration, and metacognitive reflection. They were divided into three main operational areas:

1. Collaborative construction of digital concept maps

During the first two weeks, the focus was on creating digital concept maps collectively using applications such as MindMeister and Coggle. Working in small groups of four to five members, students analysed key concepts from the science programme, such as ecosystems, energy, and interactions between species. They then developed shared graphic representations that linked these concepts and processes.

This phase was designed to stimulate processes of semantic negotiation and distributed meaning construction, in line with Dillenbourg's (1999) theory of collaborative learning and Hutchins' (1995) perspective of the distributed mind. As an external cognitive artefact, the digital concept map functioned as an extension of collective working memory, facilitating interpersonal coordination and reflection on conceptual relationships.

Recent research (Cañas et al., 2021; Fiorella & Mayer, 2022) confirms that using digital graphic representation tools enhances deep understanding, information integration, and metacognition, particularly in collaborative settings.

2. Scientific simulations and experiential learning

During the middle weeks, lessons incorporated simulations of scientific experiments using interactive apps (e.g. PhET Interactive Simulations and Lab4Physics). These allowed students to explore physical and biological phenomena that are difficult to observe in a real laboratory.

These activities employed an inquiry-based learning approach (Hmelo-Silver et al., 2007): students formulated hypotheses, tested variables, recorded data digitally and discussed the results in groups. Using simulation technologies reduced the risk of experimentation and enhanced direct interaction with the phenomenon, thereby promoting embodied and situated learning.

Using digital tools for experimentation was chosen to achieve a specific pedagogical goal: to transform technology from a consumer object into an epistemic tool (Pea, 2020). According to Clark (2008), such tools act as 'cognitive amplifiers', extending

students' ability to manipulate and understand abstract concepts. Qualitative observations showed that students tended to interpret tablets not as entertainment devices, but as genuine tools for scientific investigation. They perceived a sense of mastery and 'distributed intelligence' (Zhang & Patel, 2020), which involved collaboration between people, artefacts, and the environment.

3. Metacognitive reflection and digital diaries

The final phase of the programme involved metacognitive reflection and self-assessment activities using individual digital diaries. Over the course of five or six weeks, students were asked to document the learning strategies they used, the difficulties they encountered, and the emotions associated with the activities.

This component was inspired by Zimmerman's (2008) research on self-regulated learning, as well as the most recent applications of metacognition in digital environments (Greene et al., 2022). Students reflected on both the subject content and the physical and relational experience of learning in a sensitive, technology-mediated environment.

These written reflections were then discussed during collective reflective dialogues (Schön, 1983), in which the class analysed group dynamics and the role of digital artefacts in the cognitive process. This dialogical dimension fostered ecological awareness of learning — the perception that knowledge is continuously negotiated between body, mind, tools and space, rather than being 'internal' (Fenwick, Edwards & Sawchuk, 2020).

According to Rivoltella (2017), the entire educational design was built around the notion of educational co-evolution, which states that learning is not an individual process, but rather a phenomenon that emerges from the interaction between humans, the environment, and technology. From this perspective, smart environments not only optimise the material conditions for learning, but also help shape the very nature of cognition.

Several studies (Johnson-Glenberg, 2018; Wang et al., 2022; Bower, 2023) have highlighted that integrating sensory devices, mobile technologies, and flexible spaces can promote embodied and distributed cognitive processes, thereby increasing intrinsic motivation and cognitive engagement. Furthermore, literature on the pedagogy of smart environments (Zhou et al., 2021; Limone & Parmigiani, 2023) emphasises that technology's educational value only emerges when it is designed as part of an ecological system that supports students' autonomy and critical thinking.

The combination of collaborative, experiential, and reflective activities aimed to create an extended learning cycle (Kolb, 2015) in which action, perception, and reflection continuously intertwine to generate embodied and relational cognitive awareness.

Table 1 – Experimental Group Activities

Week	Activity	Aims	Tools	Cognitive processes stimulated
1–2	Collaborative	Organising	Tablet,	Critical thinking, semantic

Week	Activity	Aims	Tools	Cognitive processes stimulated
	construction of digital concept maps	knowledge, developing relational thinking and collaboration skills	MindMeister, interactive display, light sensors	negotiation, distributed cognition
3-4	Interactive scientific simulations and problem solving	Applying scientific concepts, testing hypotheses, promoting experiential learning	PhET, Lab4Physics, motion and temperature sensors	Hypothetical-deductive reasoning, embodied learning
5-6	Digital diaries and metacognitive reflection	Promoting self-regulation, bodily and cognitive awareness	Google Classroom Journal, feedback ambientale visivo	Metacognition, self-assessment, ecological reflection

Control Group

The control group followed the same disciplinary programme and intervention duration, but in a traditional classroom without technological devices or environmental adaptations. This was done to ensure comparability of content while maintaining different cognitive and perceptual conditions in the learning context.

Lessons were conducted according to a transmissive-laboratory model, consistent with the school's usual teaching practice. The teacher used a textbook, a traditional blackboard, and the occasional manual experiment, with no digital support or structured collaborative activities.

During the first two weeks, students in the control group developed paper-based concept maps, which they created individually and then discussed in plenary sessions. The middle weeks were devoted to observational demonstration experiments (e.g. measuring temperature and water evaporation), which were conducted by the teacher in front of the class.

The final two weeks included summary activities and oral reflections, with no digital tools or systematic self-assessment practices. Assessment of cognitive progress was based on traditional written tests and direct teacher observation.

This approach was chosen deliberately to represent the educational model that currently prevails in Italian schools, which is centred on frontal teaching and a clear separation between environment, body and knowledge. While not without educational value, this approach constitutes a form of 'pedagogy of cognitive isolation' (Rivoltella, 2022), whereby the student's mind is treated as an autonomous entity, divorced from technological and environmental contexts.

The main difference between the two groups was not only their use of technology, but also the different pedagogical ontologies implicit in their respective environments. In the experimental group, knowledge was constructed through the co-evolution of the body, space, and technology according to an ecological learning paradigm. In contrast, the control group remained confined to a linear model of transmissive teaching, where the environment acted merely as a container and not as a cognitive agent.

Therefore, the experiment contrasted not “digital school” and “analogue school”, but two epistemological models of learning: the embodied and distributed model, which views cognition as a network of relationships, and the intellectualist and centralised model, which reduces cognition to isolated mental processing.

3. Tools

In order to ensure methodological triangulation consistent with the qualitative-quantitative approach of the study, the evaluation of the outcomes of the intervention was conducted using an integrated set of standardised (quantitative) and exploratory (qualitative) tools.

This integration made it possible to measure both the objective variations in cognitive and motivational performance and the subjective and experiential dimensions of learning in intelligent environments.

3.1. Quantitative Tools

Three internationally validated tests were selected, widely used in scientific literature on cognitive and motivational processes in childhood. They were chosen based on criteria of construct validity, psychometric reliability and adherence to the research objectives.

1. d2-R Test of Attention (Brickenkamp & Zillmer, 1998): This is a standardised tool for measuring selective and sustained attention and concentration skills. The test consists of visual recognition of target stimuli within a sequence of similar characters, allowing for the calculation of accuracy, speed and attentional control indices. It was administered individually at two points in time — *pre-test* and

post-test — in a context free from sensory distractions, with an average duration of approximately 8 minutes per subject. The use of this tool responds to the need to verify whether interaction with dynamic and multisensory environments could improve the ability to maintain attention over time, as hypothesised by the research of Posner and Rothbart (2007) and more recently by Makransky & Mayer (2022) in the field of educational augmented reality.

2. Cornell Critical Thinking Test, Level X (Ennis & Millman, 1985): The test measures critical thinking skills, including dimensions such as deduction, induction, source credibility, and recognition of implicit assumptions. It was chosen for its psychometric soundness and its ability to detect variations even in school-age samples. It was administered collectively, with a time limit of 45 minutes, following the standardised instructions provided in the manual. In line with the perspective of Kuhn (2019) and Paul & Elder (2020), the aim was to observe whether participation in collaborative and multimodal contexts could foster the development of more flexible and reflective forms of argumentative thinking.

3. Academic Motivation Scale (AMS) (Vallerand et al., 1992; Italian adaptation by Alivernini & Lucidi, 2011): This tool, based on Self-Determination Theory (Deci & Ryan, 2000), investigates different types of academic motivation along a continuum ranging from intrinsic to extrinsic motivation to amotivation. The questionnaire, consisting of 28 items on a 7-point Likert scale, was administered individually. The aim was to understand whether the intelligent environment could affect the quality of motivation, favouring more self-determined and less hetero-directed forms of engagement, in accordance with recent studies on active learning in digital contexts (Reeve, 2023).

All quantitative tests were administered at two separate times: one week before the start of the intervention (pre-test) and one week after its conclusion (post-test), under equivalent environmental conditions for both groups.

3.2. *Qualitative tools*

Alongside psychometric measures, a qualitative methodology was adopted to explore the experiential, bodily and relational dimensions of learning. In line with Creswell & Plano Clark's (2018) recommendations on the mixed methods approach, the qualitative investigation aimed to interpret and contextualise the quantitative results, offering a deeper understanding of the underlying processes. Three main qualitative tools were used:

1. Participant observations: Teacher-researchers conducted systematic observations during all phases of the intervention, noting interaction dynamics,

emotional participation, attention management, and peer cooperation in structured observation grids. The observations followed a phenomenological approach (Mortari, 2015), aimed at capturing the quality of the educational experience as it emerged in its context, paying particular attention to physicality and the use of technological artefacts as cognitive mediators (Suchman, 2007).

2. Post-intervention focus groups: Three focus groups (average duration: 60 minutes) were organised with students from the experimental group, selected to ensure gender balance and representativeness in terms of performance. The guiding questions explored the subjective perception of learning, the relationship with technology, bodily awareness and motivation. The protocol was inspired by the methodology of Krueger & Casey (2015), encouraging open and reflective discussion.

3. Students' digital diaries: Already introduced as an integral part of the teaching intervention (see §2.2), digital diaries were considered primary qualitative sources, as they allow access to individual reflection and the narrative construction of experience (Clarà, 2021). The texts were collected, anonymised and analysed in conjunction with the focus group minutes to identify common thematic patterns.

4. Analysis

4.1 Quantitative Analysis

The data from the three standardised tests were analysed using SPSS software (version 28).

After verifying the assumptions of normality and homogeneity of variance, the following were performed:

- t-test for independent samples to compare the post-test scores of the two groups;
- t-test for paired samples to analyse intra-group variations between pre- and post-test;
- Effect Size calculation (Cohen's d) to assess the magnitude of the observed effects;
- Pearson correlation analysis between improvements in attention, critical thinking and motivation scores.

This approach made it possible to rigorously quantify the impact of the intelligent environment on cognitive and motivational processes, in line with the validation procedures of similar experimental studies (Makransky & Lilleholt, 2018).

5. Qualitative analysis and interpretative triangulation

The qualitative materials (focus group transcripts, digital diary excerpts, and observation grids) underwent thematic analysis according to the model developed by Braun & Clarke (2006; 2021). The procedure consisted of six stages:

1. Familiarisation with the data – exploratory reading and annotation of first impressions;
2. Initial coding – identification of units of meaning relevant to the themes of corporeality, interaction, reflection and motivation;
3. Search for recurring themes – grouping of codes into conceptual clusters (e.g. “distributed attention”, “technology as extension”, “ecological motivation”);
4. Review and refinement of themes – verification of internal and external consistency;
5. Definition and naming of main themes;
6. Integrated interpretation – comparison with quantitative data to develop a coherent narrative of the results.

The reliability of the coding was ensured by a double coding process: two independent researchers analysed the data, reaching an inter-coder agreement of 92% (Cohen's $\kappa = 0.87$). The thematic analysis identified three emerging dimensions:

1. cognitive embodiment as a mediator of attention;
2. the interactive co-construction of knowledge through artefacts;
3. situated intrinsic motivation, linked to a sense of agency and environmental participation.

Finally, the qualitative and quantitative results were triangulated according to the *convergent parallel* approach (Creswell & Plano Clark, 2018), in order to obtain an integrated view of the phenomena observed.

6. Results

6.1. Quantitative Results

Statistical analysis of the data revealed significant differences between the experimental and control groups in all three investigated domains — sustained attention, critical thinking and academic motivation — confirming the programme's effectiveness in the intelligent environment.

The d2-R Test of Attention showed an average concentration score increase of 19.8% in the experimental group between the pre- and post-tests ($t(29)=4.31$, $p<.001$, $d=0.79$), compared to a marginal 4.2% increase in the control group ($t(29)=1.12$, n.s.).

A significant main effect between groups was observed at the post-test stage ($t(58)=3.98$, $p<.001$), indicating that prolonged exposure to an adaptive,

multisensory environment enhances the capacity to sustain attention over time. These findings align with Makransky and Mayer's (2022) hypothesis that well-designed immersive technological environments amplify attentional control by simultaneously modulating perceptual and cognitive channels. The automatic adjustment of brightness and noise, combined with the spatial variability of the smart classroom, appears to have helped create a perceptual context that promotes focus, in line with Gallagher's (2017) theory of embodied attention. In the Cornell Critical Thinking Test, the experimental group achieved an average improvement of 14.5% compared to the pre-test ($t(29)=3.76$, $p<.01$, $d=0.68$), whereas the control group demonstrated a less significant improvement of 5.1% ($t(29)=1.43$, n.s.). Comparing the post-intervention groups ($t(58)=2.91$, $p<.01$) confirms that learning mediated by cognitive artefacts and collaborative activities promotes the development of critical reasoning strategies, probably due to the negotiation of meanings and shared knowledge construction. These results are consistent with the work of Kuhn (2019) and Paul and Elder (2020), who argue that critical thinking emerges from contexts of reasoned discussion rather than unidirectional content transmission. The intelligent environment, as a socio-technical network (Latour, 2005), provided the cognitive and relational foundation necessary for ideas to circulate, be questioned, and be reworked collectively. Finally, scores on the Academic Motivation Scale (AMS) revealed a notable increase in intrinsic motivation (+21.3%) within the experimental group, alongside a decline in amotivation (-12.5%). Conversely, the control group exhibited a modest decrease in intrinsic motivation (-3.8%) and an increase in extrinsic motivation (+5.2%). A post-test intergroup comparison ($t(58) = 3.64$, $p < .001$) suggests that the intelligent environment promoted self-determined involvement, in line with Deci and Ryan's (2000) Self-Determination Theory. This result can be interpreted in light of the principle of ecological agency (Barab & Roth, 2006). When students perceive that their actions have a tangible impact on the environment — as with sensors and visual feedback — their sense of control and the personal meaning they attribute to learning increases.

**Table 2 - shows the quantitative results of the pre- and post-comparison
between the experimental and control groups.**

Variable	Tool	Group	Pre-test (M $\pm$ SD)	Post-test (M $\pm$ SD)	$\Delta\%$	t (df)	p	Interpretation
Sustained attention	d2-R Test of Attention	Experimental (N=30)	56.3 $\pm$ 8.4	67.4 $\pm$ 7.1	+19.8%	4.31 (29)	< .001	Significant improvement in sustained attention thanks to multisensory and adaptive modulation of the intelligent environment.
		Control (N=30)	55.7 $\pm$ 7.9	58.0 $\pm$ 8.2	+4.2%	1.12 (29)	n.s.	No significant changes; attention stable in traditional context.
Critical thinking	Cornell Critical Thinking Test (Level X)	Experimental	42.1 $\pm$ 6.8	48.2 $\pm$ 6.1	+14.5%	3.76 (29)	< .01	Significant increase in analytical and inferential skills through collaborative and reflective activities.
		Control	43.5 $\pm$ 6.5	45.7 $\pm$ 6.9	+5.1%	1.43 (29)	n.s.	Slight improvement, not significant.
Academic motivation (intrinsic)	Academic Motivation Scale (AMS)	Experimental	4.1 $\pm$ 0.6	5.0 $\pm$ 0.5	+21.3%	3.64 (29)	< .001	Increase in intrinsic motivation and perception of ecological agency.

Variable	Tool	Group	Pre-test (M $\pm$ SD)	Post-test (M $\pm$ SD)	$\Delta\%$	t (df)	p	Interpretation
		Control	4.2 $\pm$ 0.5	4.0 $\pm$ 0.6	-3.8%	0.98 (29)	n.s.	Slight decline in motivation; prevalence of extrinsic motivations.

Note. $\Delta\%$ indicates the percentage change between pre- and post-test. All t-tests are two-tailed.

6.2. Qualitative Results

A thematic analysis of qualitative materials (digital diaries, focus groups and participant observations) produced three macro-themes that help to explain the quantitative results and interpret learning processes from a co-evolutionary cognitive perspective.

Many students in the experimental group described their experience of attention as 'physical', talking about 'moving to think better' or 'feeling concentration in the body'.

Observations showed that moments of greatest engagement coincided with activities requiring coordinated movement and direct device manipulation.

These findings support the hypothesis of embodied cognition (Berthoz, 2009; Sibilio, 2014), which states that cognition is not confined to the mind, but rather manifests itself as a distributed sensorimotor process. Students did not merely 'use' technology; they co-evolved with it through bodily action, engaging in a continuous exchange of perceptual stimuli and cognitive adjustments.

In focus groups, participants often emphasised that they 'understood better when they worked together' and that 'ideas became clearer when they talked and corrected each other'.

These qualitative findings are consistent with theories of distributed cognition (Hutchins, 1995) and learning by design (Kolodner et al., 2003). According to these theories, knowledge is never the product of an isolated mind, but rather the result of a social and material system that encompasses tools, language, and gestures.

In the intelligent environment, technology acted as a mediating artefact capable of making collective thinking visible (through concept maps and shared feedback) and encouraging dialogic reflection (Schön, 1983).

A third strong theme that emerged concerns the perception of the environment as a

relational agent. Students described the classroom as 'responding to you' or 'understanding you when you are distracted'.

This anthropomorphic language suggests a shift in perception from technology as an object to technology as a cognitive partner. This confirms the hypotheses of Rivoltella (2017) and Latour (2005) on the symbiotic nature of socio-technical networks.

Therefore, motivational engagement did not stem solely from technological novelty, but from a sense of connection with the environment. Technology was not an obstacle or a distraction, but rather an extension of the cognitive self capable of providing immediate and meaningful feedback.

Table 3 – Qualitative results: themes emerging from the pre- and post-comparison (thematic analysis)

Topic	Description	Evidence from the experimental group (post)	Control group evidence (post)	Pedagogical interpretation
1. Corporeality and embodied attention	Attention is perceived as a physical experience and distributed between body and space.	Students describe “moving to think better” and “feeling concentration in the body”.	No mention of physical size; attention described as “effort” or “mental exertion”.	This confirms the theory of embodied cognition (Berthoz, 2009): the intelligent environment promotes situated and multisensory attentional regulation.
2. Social co-construction of knowledge	Learning is experienced as a dialogical and shared process.	Frequent descriptions of “understanding better together”, “correcting each other”.	Focus on listening to the teacher and on individual assignments.	It supports the perspective of distributed cognition (Hutchins, 1995): knowledge emerges from the social and material network of the classroom.
3. Ecological motivation and agency	The environment is perceived as an interactive and motivating actor.	Expressions such as “the classroom responds to you”, “it understands when you are distracted”.	The classroom is described as a static and neutral space.	Validates the idea of ecological pedagogy (Rivoltella, 2022): environmental reciprocity promotes intrinsic motivation

Topic	Description	Evidence from the experimental group (post)	Control group evidence (post)	Pedagogical interpretation
				and a sense of belonging.

7. Discussion

This research demonstrates how intelligent learning environments can facilitate deeply integrated cognitive, affective and metacognitive processes. Quantitative data reveal a statistically significant enhancement of sustained attention, critical thinking and intrinsic motivation within the experimental group. Meanwhile, qualitative analysis offers an experiential perspective, depicting learning as an embodied, relational act distributed between the body, tools and environment.

The convergence of these two analytical perspectives confirms that the effectiveness of an intelligent environment depends not only on the presence of technology, but also on the ecological structuring of the context — a space designed to support and enhance the natural dynamics of attention, interaction and reflection.

In the experimental group, technology was not experienced as a distraction, but rather as a cognitive prosthesis (Clark, 2008; Clark & Chalmers, 1998): a natural extension of the mind capable of enhancing working memory, representation, and interpersonal coordination. This perception is clearly evident in the digital diaries and post-intervention focus groups, where students describe the devices as 'part of thought itself' rather than external tools. These findings confirm the extended mind theory, which states that cognitive resources are distributed throughout the human-environment-technology system (Menary, 2010; Newen et al., 2018).

The triangulation of quantitative and qualitative data enables us to propose a meta-disciplinary vision of learning as an emerging phenomenon that is consistent with the theoretical framework of the call 'Pedagogies of Co-evolution'. The intelligent environment, configured as a sensitive cognitive ecosystem, acted on three fundamental levels: Cognitive: the dynamic distribution of cognitive resources between the body, space, and digital tools increased sustained attention (d2-R) and inference skills (Cornell CTI).

1. Students experienced forms of 'situated attention' (Gallagher, 2017), whereby concentration arose from the coordination of perception, movement, and technological interaction. This suggests that attentive management is a relational practice mediated by context, rather than an act of internal control (Roda & Nabeth, 2020).

2. Metacognitive (reflection and self-regulation): the use of digital diaries, light feedback systems and self-assessment tools stimulated processes of conscious reflection. Students evolved in their use of metacognitive language, progressing from episodic descriptions such as 'Today I concentrated more' to more analytical forms such as 'It helps me to understand better if I change position or light'. These findings support Flavell's (1979) theories on the significance of cognitive awareness, as rein-

terpreted by Sibilio (2014) and Damasio (2021). According to these authors, cognitive regulation involves the involvement of the body and emotions as informative signals.

3. Motivational (agency and meaning): the experimental group reported a significant increase in intrinsic motivation (AMS), accompanied by a sense of agency and environmental belonging. The fact that students describe the classroom as “a space that responds” or “understands you” demonstrates the construction of an affective and intentional relationship with the environment (Biesta, 2022). This type of ecological reciprocity, as Rivoltella (2022) notes, represents a new frontier in digital pedagogy: no longer learning *with* technology, but learning *in* technology, in a system that adapts and co-evolves with the subjects.

From a broader perspective, these findings call into question the pedagogical legitimacy of policies that exclude technology from Italian schools. If, as Clark (2008), Berthoz (2009) and Sibilio (2014) argue, cognition is an embodied, extended and distributed process, then banning the use of digital devices is equivalent to reducing the cognitive field within artificial boundaries. Rather than protecting concentration, the ban results in a kind of 'cognitive deprivation', preventing students from developing the ability to think critically and regulate their own use of technology (Rivoltella & Rossi, 2019).

The smart classroom tested in this study does not coincide with the “digital school” model in the instrumental sense, which is often criticised for its technocentrism (Selwyn, 2016). Instead, it embodies a co-evolutionary and relational vision of teaching, in which knowledge emerges from a socio-technical network comprising students, teachers, objects, and environments. In this sense, the school setting becomes a pedagogical actor (Latour, 2005), actively participating in the construction of knowledge rather than being a simple, neutral container.

The experiment also demonstrates that space design is a crucial pedagogical variable. Adjustments to light, sound, and body posture have enabled the embodiment of the theory of embodied cognition, transforming learning into a sensory, situated experience. These findings are consistent with van Merriënboer and Kirschner's (2018) research on the importance of distributed cognitive load and more recent studies by Barabási (2021), which interpret cognition as a dynamic network of plastic connections.

The qualitative dimension also emphasised the importance of movement and physicality: students reported that 'thinking while standing' or 'moving around the room' helped them to understand concepts more easily. This confirms the epistemic function of the body in cognitive processes, a concept previously theorised by Berthoz (2009) and recently revisited by Noë (2021). According to Noë, intelligence is not localised, but rather emerges from sensorimotor dialogue with the world.

From a multidisciplinary perspective, the study contributes to the debate on co-evolutionary pedagogies by proposing a learning model that integrates the cognitive, technological, and environmental dimensions into one ecological continuum. The intelligent environment is not merely a support; it is an ontological condition of contemporary learning. In this sense, technology is not an addition, but a constitutive component of the extended mind.

Ultimately, the survey suggests that schools should educate students in the cognitive ecology of digital technology, rather than limiting or monitoring the use of devices. This involves training individuals to move consciously between tools, environments

and bodies, recognising the interdependent relationships that underpin knowledge. As Rivoltella (2023) states, 'Digital education is not a question of access to technology, but of access to the cognitive relationships that technology makes possible'. Therefore, the general ban on smartphones in the classroom appears anachronistic and reductive: rather than protecting attention, it impoverishes it by depriving students of the opportunity to experience the cognitive complexity of their own world. Educating within the human–environment–technology network means building sensitive and reflective spaces where the mind can expand, interact with, and transform alongside the artefacts and contexts that inhabit it.

8. Conclusion

The results of this research confirm that intelligent learning environments are crucial for redefining contemporary pedagogy. The experiment showed that intentionally integrating technological, sensory and spatial elements not only supports learning, but also triggers a structural transformation in students' cognitive, motivational and relational processes.

The intelligent environment is configured as a space for cognitive co-evolution, where knowledge emerges from the interaction between the mind, body, and artefacts, rather than being transmitted. Not only is there an increase in performance (attention, critical thinking and motivation), but a different form of cognitive presence is also activated, characterised by greater awareness, reflectiveness and sensorimotor involvement.

From a pedagogical point of view, these results encourage us to move beyond the dichotomy of the 'traditional school' versus the 'digital school' to achieve an ecological vision of education (Rivoltella, 2022; Biesta, 2023).

From this perspective, technology is not just a tool; it is a component of the extended learning system and a participant in the educational process, equal to the teacher, physical space and social group. The experimental approach adopted has demonstrated that the presence of sensitive and adaptive technologies, such as light feedback, interactive apps and modular spaces, promotes not only concentration and cooperation, but also the development of a sense of cognitive agency. Students do not merely 'use' technology; they 'dialogue' with it. This reversal of perspective is fundamental to designing post-digital educational practices (Fawns, 2022), in which learning is always embodied, distributed, and situated within a complex, relational environment.

In terms of educational policy, the study calls for critical reflection on current Italian ministerial directives that limit or prohibit the use of digital devices in schools. If, as Clark (2008), Berthoz (2009) and Sibilio (2014) argue, cognition is an extended and multisystemic process, then technological exclusion risks constituting real institutionalised cognitive deprivation. Digital education cannot be based on prohibitive logic; rather, it must be founded on a paradigm of reflective regulation that teaches students to manage the complexity of their cognitive ecosystem.

From this perspective, the need for a pedagogy of co-evolution emerges (Rivoltella, 2022; Floridi, 2023), which conceives of learning as a continuous process of negotiation between humans, environments, and technologies. Intelligent environments offer a privileged space in which to experiment with this model by making the cognitive relationships that normally remain implicit — such as the effect of light on attention, sound on memory and spatial arrangement on collaboration — visible and

modifiable.

The operational implications of these findings are manifold:

- Teacher training: *ecological mediation* skills need to be developed, enabling teachers to design cognitively sensitive environments by regulating spatial, physical and technological variables in an integrated manner.
- School design: architects, educationalists and designers must collaborate to create flexible and interactive spaces in which the environment itself becomes a teaching tool.
- Curriculum and assessment: it is necessary to introduce forms of ecological assessment capable of measuring not only cognitive results but also the relational and reflective quality of the learning experience.

In terms of scientific research, this study opens up at least three areas for further investigation:

1. Longitudinal analysis of the effects of intelligent environments on cognitive and motivational development, to verify the persistence of benefits over time;
2. The neuroscientific and physiological exploration of the bodily correlates of situated attention, through non-invasive monitoring techniques (EEG, eye-tracking, biometric sensors);
3. The social and cultural dimension of cognitive co-evolution, to understand how technological mediation transforms class group dynamics and the construction of shared meaning.

Looking ahead, school could become a place where we learn to think ecologically — that is, to recognise our own minds as part of a broader cognitive ecosystem. In this sense, the intelligent environment is not merely a place of learning; it is also an epistemic device that teaches us to think in a connected, situated and responsible way. As Floridi (2023) writes, we now live in an 'infosphere' where the boundaries between reality and the digital realm, and between humanity and technology, are ontologically intertwined. Educating within the network of humans, the environment and technology therefore means training individuals to engage with this interconnection in a conscious, ethical and creative way.

In conclusion, the experiment presented in this study invites us to rethink the meaning of education itself: not the mere transmission of knowledge, but rather the co-construction of cognitive ecologies. The learning mind is not an isolated entity to be protected from the world; it is a node in a constantly changing network.

Prohibiting technology, therefore, is tantamount to denying the reality of contemporary cognition.

The only sustainable pedagogical approach is reflective integration: education that embraces technology as a condition of our cognitive humanity, rather than viewing it as a threat.

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