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Extended learning environments as distributed cognitive systems: Effects of a hybrid educational ecosystem on cognition, motivation, and participation in primary school

Davide Di Palma [1]

[1] University of Campania "Luigi Vanvitelli"; davide.dipalma@unicampania.it

Abstract: Recent research increasingly conceptualises learning environments as active components of cognitive and educational processes. Drawing on the perspectives of the extended mind and ecological cognition, this study investigates the effects of a hybrid learning ecosystem—integrating classroom, outdoor, and digital environments—on primary school students' development. A quasi-experimental design was conducted with 120 students (aged 8–10), divided into experimental and control groups, including students with Special Educational Needs (SEN) and Specific Learning Disorders (SpLD). The 16-week intervention involved structured activities across hybrid learning environments. Data were collected through validated psychometric instruments and qualitative observations using pre- and post-intervention measures. Results show significant improvements in the experimental group in executive functions, school motivation, social participation, and perception of the learning environment. These findings suggest that extended learning environments function not merely as contexts but as components of distributed cognitive systems that actively shape learning processes. The study contributes empirical evidence to ecological and relational approaches to education and to the understanding of hybrid educational ecosystems.

Keywords: extended learning environments, distributed cognition, hybrid learning ecosystems, primary education, student participation

1. Introduction

The technological, social, and cultural transformations that characterize contemporary societies are progressively redefining the nature of learning environments and the role they play in educational processes. The expansion of digital technologies, the increasing interconnectedness between formal and informal settings, and the diffusion of flexible and hybrid learning spaces have challenged the traditional conception of schools as closed and self-sufficient institutions. In this scenario, the classroom can no longer be conceived as a static and bounded space, but rather as a component of a broader system of relationships, tools, practices, and contexts that contribute to the construction of educational experience (Goodyear & Carvalho, 2014; Carvalho & Yeoman, 2018).

Within this evolving landscape, a growing body of research in cognitive science and educational theory has questioned the idea that learning can be fully understood as an internal process confined to the individual mind. Instead, learning is increasingly conceptualized as a situated, distributed, and ecologically mediated process that emerges from the interaction between individuals, cultural artefacts, physical environments, and social contexts (Hutchins, 1995; Lave & Wenger, 1991). From this perspective, the environment is not merely the background of cognitive activity, but an active component of knowledge construction. More radically, it participates in the constitution of the cognitive system itself, becoming an intrinsic element of learning dynamics.

Learning processes do not arise from an isolated subject interacting with external tools, but from relational systems in which subjects, environments, and artefacts co-evolve and co-determine cognitive activity. This implies a significant epistemological shift: from a conception of the mind as extending outward to that of a distributed cognitive system emerging from the dynamic relationships between heterogeneous elements. Learning environments, therefore, do not simply support cognition; they actively contribute to its organization, regulation, and transformation.

The theoretical perspectives of the extended mind (Clark & Chalmers, 1998) and distributed cognition (Hutchins, 1995) provide a foundational framework for understanding these transformations. These perspectives are further enriched by the seminal contribution of Gregory Bateson, whose ecological epistemology anticipates many of the assumptions underlying contemporary theories of distributed cognition. According to Bateson (1972), the mind cannot be reduced to the brain or the individual, but must be understood as a systemic and relational process emerging from circuits of interaction between organism and environment. Cognitive processes are thus embedded in feedback loops through which differences are perceived, transformed, and reorganized within the system.

Within this perspective, learning can be interpreted as a transformation of relational patterns rather than as the mere internal acquisition of content. Educational environments, therefore, function as systems characterized by recursive dynamics and feedback processes, in which students, teachers, cultural artefacts, and technologies jointly contribute to the emergence of knowledge. Learning assumes an ecological nature, grounded in the continuous interaction between heterogeneous elements within dynamic systems (Barron, 2006).

In recent years, the evolution of digital technologies has further expanded this perspective, introducing increasingly complex and interconnected learning environments that integrate physical, digital, and social dimensions. Hybrid learning environments enable the development of distributed educational experiences that transcend the boundaries of traditional classrooms, incorporating outdoor spaces, digital platforms, and community contexts (Goodyear & Carvalho, 2014). These environments support more flexible and participatory forms of learning, fostering collaboration, access to diverse resources, and the development of competencies through experiences distributed across multiple contexts.

More recently, the emergence of artificial intelligence has introduced a further qualitative shift in the configuration of learning environments. Digital systems are no longer limited to supporting learning processes but increasingly participate in organizing information, guiding decision-making, and shaping educational practices. From this perspective, technological artefacts can be interpreted as *agential components* within educational ecosystems, capable of influencing cognitive processes through mechanisms of anticipation, suggestion, and adaptive feedback (Luckin et al., 2016; Holmes et al., 2022). This development reinforces the need to conceptualize learning environments not as passive contexts, but as active elements within distributed cognitive systems.

Despite the growing theoretical attention to extended and hybrid learning environments, much of the existing literature remains predominantly descriptive. In particular, experimental studies systematically investigating the impact of extended educational ecosystems on cognitive, motivational, and socio-relational processes—especially in primary education—are still relatively limited. This gap is particularly significant given that primary school represents a crucial stage in children's cognitive and social development, during which core functions such as attention, working memory, collaboration, and emotional regulation are shaped.

In light of these considerations, the present study aims to contribute to the scientific debate on extended learning environments through an experimental investigation focused on the effects of a hybrid educational ecosystem integrating physical spaces, outdoor environments, and collaborative digital tools. Specifically, the study examines how participation in an extended learning environment influences the development of cognitive functions, school motivation, and social skills in primary school students, with particular attention to students with Special Educational Needs (SEN) and Specific Learning Disorders (SpLD).

Adopting a quasi-experimental design with a mixed-methods approach, the study seeks to provide empirical evidence on the role of educational environments in shaping learning processes. In doing so, it contributes not only to the evaluation of the effectiveness of extended learning environments, but also to the broader understanding of learning as a distributed and system-based phenomenon within contemporary educational ecosystems.

2. Objectives and Hypotheses

Objectives

The present study aims to investigate the role of extended and hybrid learning environments as structuring conditions of cognitive, motivational, and socio-relational processes in primary education.

Specifically, the objectives are:

- to examine the effects of extended learning environments on students' executive functions (selective attention, working memory, and cognitive flexibility);
- to assess the impact of hybrid learning environments on school motivation and student participation;
- to analyse the social dynamics emerging within ecologically designed learning contexts;
- to evaluate the effectiveness of extended learning environments in supporting participation and inclusion among students with Special Educational Needs (SEN) and Specific Learning Disorders (SpLD).

Hypoteses:

In line with ecological and distributed cognition perspectives, the study tests the following hypotheses:

1. Students in the experimental group will show significantly greater improvements in executive functions compared to the control group.
2. Participation in hybrid learning environments will be associated with higher levels of school motivation and student engagement.
3. Extended learning environments will foster increased social interaction and peer collaboration.

4. Students with SEN and SpLD in the experimental group will show improvements in participation and perceived self-efficacy compared to their counterparts in the control group.

3. Methods

The study adopts a quasi-experimental longitudinal design with a mixed-methods approach, aimed at investigating the effects of an extended and hybrid learning ecosystem on students' cognitive, motivational, and socio-relational processes.

The use of a mixed-methods design allows for the integration of quantitative data—collected through standardised instruments—with qualitative data aimed at capturing the complexity of educational and relational dynamics within learning environments. This approach is particularly appropriate when investigating educational interventions in real-world contexts, where controlled experimental conditions are often not feasible.

The quasi-experimental design was chosen due to the organisational constraints of the school setting, which did not allow for random assignment of students to experimental conditions. Instead, intact classroom groups were assigned to experimental and control conditions, ensuring ecological validity while maintaining comparability between groups.

The study involved two groups:

- an experimental group, which participated in an educational programme based on extended and hybrid learning environments integrating classroom, outdoor, and digital contexts;
- a control group, which followed the standard school curriculum delivered primarily through traditional classroom-based instruction.

Both groups were assessed using pre- and post-intervention measures, allowing for the analysis of changes over time and between-group comparisons.

The intervention lasted 16 weeks, a duration considered sufficient in educational research to observe meaningful changes in cognitive and socio-relational processes.

In parallel with quantitative data collection, qualitative data were gathered through:

- systematic classroom observations,
- teacher reflective notes,
- semi-structured interviews,
- student focus groups.

This integration enables not only the identification of measurable outcomes but also the interpretation of how learning environments structure interactional and educational processes.

3.1. Sample

The sample consisted of **120 primary school students aged between 8 and 10 years**, a developmental stage characterised by significant consolidation of executive functions, social skills, and learning strategies.

Participants were divided into two groups:

- Experimental group (n = 60)
- Control group (n = 60)

Group allocation was based on **pre-existing classroom groups**, while ensuring balance in terms of age, gender, and presence of students with SEN and SpLD, in order to enhance comparability between conditions.

A relevant feature of the sample is the inclusion of students with:

- Special Educational Needs (SEN)
- Specific Learning Disorders (SpLD)

Distribution:

- Experimental group: 12 students
- Control group: 11 students

The inclusion of these students in both groups allows for a more robust evaluation of the intervention's impact in inclusive educational contexts.

Participants were required to meet the following criteria:

- age between 8 and 10 years;
- regular school attendance;
- informed consent from parents or legal guardians;
- eligibility to participate in all planned educational activities.

To ensure internal validity, the following exclusion criteria were applied:

- severe neurological or clinical conditions affecting cognitive functioning;
- severe motor impairments limiting participation in outdoor activities;
- absence from more than 25% of intervention sessions.

These criteria were adopted to reduce potential confounding variables and ensure that observed effects could be meaningfully attributed to the intervention.

4. Tools

In order to analyse in a comprehensive manner the effects of the intervention on the students involved in the study, a battery of standardised assessment tools validated in the international scientific literature was employed. The selection of instruments was guided by the aim of investigating, in an integrated way, different dimensions of student development, including cognitive, motivational, social and psychological aspects. This approach made it possible to obtain a multidimensional evaluation of the effects of extended learning environments on educational processes. The selected instruments were administered both in the pre-intervention phase and in the post-intervention phase, in order to compare any changes in the variables considered. Alongside the collection of quantitative data, the study also included the collection of qualitative data, with the aim of further exploring the relational and instructional dynamics that develop within extended learning environments.

Cognitive function

The assessment of cognitive functions focused in particular on three fundamental dimensions of cognitive processes in school-age children: selective attention, working memory and cognitive flexibility. These components fall within the broader construct of executive functions, which are considered central to school learning and behavioural regulation (Diamond, 2013; Miyake et al., 2000). Selective attention was assessed using the Bells Test, a tool widely employed in the neuropsychological assessment of children (Biancardi & Stoppa, 1997). The test consists of a visual search task in which the student is required to identify and mark specific target stimuli within a matrix of similar symbols. The task allows for the evaluation of concentration, speed of information processing, and the ability to discriminate relevant stimuli from distractors. The Bells Test is also frequently used in the assessment of attentional difficulties in school contexts. Working memory was assessed through the Digit Span subtest of the WISC-V (Wechsler Intelligence Scale for Children) (Wechsler, 2014). In this task, the student is required to repeat sequences of numbers presented verbally by the examiner, both in the same order (digit span forward) and in reverse order (digit span backward). The test makes it possible to measure the ability to retain and manipulate information in short-term memory, a cognitive function that is particularly relevant in learning processes, text comprehension and problem-solving (Baddeley, 2003). Cognitive flexibility was assessed using the Trail Making Test (TMT), a tool widely used in the evaluation of executive functions (Reitan, 1958; Reitan & Wolfson, 1985). The test consists of two parts: in the first (TMT-A), the student is required to connect a sequence of numbers in ascending order, while in the second (TMT-B), they must alternate between numbers and letters following a predetermined sequence. The difference in completion times between the two parts provides an indication of the ability to switch rapidly from one cognitive strategy to another, a key competence in complex learning contexts.

Participation and motivation

Students' active participation in educational activities and their level of academic motivation were assessed using two instruments commonly employed in educational research. The Student Engagement Scale was used to evaluate the level of students' involvement in school activities. This instrument measures several dimensions of engagement, including behavioural participation in learning activities, cognitive interest in learning tasks, and emotional involvement in school activities. In the educational literature, engagement is considered one of the main indicators of the quality of the learning experience (Fredricks, Blumenfeld, & Paris, 2004; Lam et al., 2014). The Motivated Strategies for Learning Questionnaire (MSLQ) was used to analyse the motivational and metacognitive strategies adopted by students during learning activities (Pintrich et al., 1991). The questionnaire allows for the assessment of dimensions such as intrinsic motivation, perceived self-efficacy, interest in school activities, and the use of cognitive and metacognitive strategies. The use of this instrument made it possible to examine the extent to which extended learning environments may influence students' motivation and self-regulation.

Social skills

Students' social skills were assessed using the Social Skills Rating System (SSRS), a tool widely used in educational and psychological research to analyse children's social behaviour in school contexts (Gresham & Elliott, 1990). The questionnaire allows for the evaluation of various dimensions of social skills, including cooperation, assertiveness, responsibility and self-control. Through the SSRS, it was possible to examine how participation in collaborative and distributed learning environments may influence relational dynamics among students and the development of fundamental social skills for group work and participation in school life.

Psychological well-being

Students' psychological well-being was assessed using two complementary instruments. The Strengths and Difficulties Questionnaire (SDQ) is a psychological screening tool used to evaluate various aspects of children's emotional and social behaviour (Goodman, 1997). The instrument examines five main dimensions: emotional problems, behavioural problems, hyperactivity/inattention, peer relationship difficulties and prosocial behaviour. The SDQ is widely used in educational and clinical research to identify potential emotional or behavioural difficulties in school-age children. The Self-Perception Profile for Children (SPPC) was used to analyse students' perceptions of their own abilities and personal worth (Harter, 1985). The questionnaire allows for the assessment of several dimensions of self-perception, including scholastic competence, peer relationships, athletic competence and global self-esteem. This instrument makes it possible to understand how learning environments may influence students' sense of self-efficacy and their psychological well-being.

Qualitative data collection

Alongside the quantitative instruments, the study included a qualitative component aimed at gaining a deeper understanding of the educational and relational dynamics that emerge in extended learning environments. Systematic observations were conducted during the teaching activities of the experimental group, with the aim of analysing students' behaviour, peer interaction patterns and the teaching strategies employed by teachers. The observations were recorded using structured grids that allowed for the documentation of specific behavioural indicators. In addition, semi-structured interviews were carried out with the teachers involved in the project, in order to gather their perspectives on the learning dynamics observed during the intervention and on the impact of extended learning environments on teaching practices. Finally, focus groups were organised with small groups of students from the experimental group. These sessions made it possible to collect information on students' perceptions of the learning environments used, the activities carried out and the ways in which they collaborated with their peers. The integration of quantitative and qualitative data made it possible to achieve a more comprehensive understanding of the effects of the intervention, enabling the analysis not only of outcomes measurable through standardised tests, but also of the transformations in the educational and relational dynamics that characterise extended learning environments.

Psychometric properties

All instruments employed in the study have been widely validated in the international literature and have demonstrated adequate reliability and validity in school-age populations. In the present study, internal consistency indices were satisfactory across the main scales, with Cronbach's alpha coefficients ranging from acceptable to good levels ($\alpha > .70$). This supports the reliability of the measures used to assess cognitive, motivational, social, and psychological dimensions.

5. Activities

The intervention was structured on a weekly basis, with a combination of classroom, outdoor, and digital activities integrated into regular teaching time. Each week included:

- at least one activity in a flexible classroom setting,
- one outdoor or contextualised learning activity,
- one digitally mediated collaborative task.

Teachers involved in the experimental group received initial guidance on the design and implementation of hybrid learning activities to ensure consistency across sessions.

The educational intervention was designed with the aim of exploring the educational potential of extended and hybrid learning environments, understood as ecosystems in which physical spaces, natural environments and digital tools interact in supporting students' cognitive, social and motivational processes. The design of the activities was based on a pedagogical perspective that considers learning as a situated and distributed process, in which the interaction between individuals, environments and cultural artefacts contributes to the construction of knowledge. From this perspective, learning environments are not merely containers for teaching activities, but active components of the cognitive and organisational systems that support the educational experience. As highlighted in the literature on situated and distributed cognition, the characteristics of educational environments can significantly influence the ways in which students process information, collaborate with one another and participate in learning activities (Hutchins, 1995; Lave & Wenger, 1991). The intervention involved only the experimental group and was carried out over a period of sixteen weeks, during which the teaching activities were designed to integrate three different types of learning environments: the flexible classroom, outdoor spaces and a collaborative digital platform. This integration was intended to create an educational ecosystem in which students could experience forms of learning distributed across different physical and digital contexts.

Flexible classroom

A first component of the intervention concerned the reorganisation of the classroom according to principles of flexibility and modularity. The environment was arranged to support different spatial configurations, with movable tables, group work areas and spaces dedicated to whole-class discussion. The literature on the design of learning environments highlights how the arrangement of space and furniture can influence interaction dynamics between students and teachers, either facilitating or hindering forms of collaborative learning (Carvalho & Yeoman, 2018). Flexible environments enable students to move quickly from individual activities to group work, supporting processes of active participation and the shared construction of knowledge. During classroom activities, students were involved in various types of collaborative tasks, including guided discussions, problem-solving activities and group work. The organisation of the space facilitated the spontaneous formation of small working groups and encouraged peer interaction, elements considered fundamental in socioconstructivist theories of learning.

Outdoor spaces

A second component of the intervention involved the use of outdoor spaces, in particular the school garden and several urban environments located near the school. The integration of outdoor activities was designed to broaden learning opportunities through situated and contextualised experiences. Educational research has shown that outdoor learning can support the development of cognitive, social and emotional skills through direct interaction with the natural and social environment (O'Neill et al., 2024; Rickinson et al., 2004). Outdoor activities allow students to observe real phenomena, explore authentic contexts and develop skills through direct experience. During the intervention, students took part in various exploration and environmental problem-solving activities. For example, some activities involved collecting data on the natural context of the school garden, observing elements of the urban environment and solving tasks that required the interpretation of information present in the surrounding environment. These activities were designed to foster the development of critical thinking and observational skills, encouraging students to formulate hypotheses, discuss their observations and collaborate in constructing solutions to the proposed problems.

Collaborative digital platform

The third component of the intervention involved the use of a collaborative digital platform that enabled students to share materials, document their activities and collaborate on the development of joint projects. Digital technologies were used as tools to support collaborative learning processes and reflection on the activities carried out across different environments. Through the platform, students were able to upload photographs, notes and short reports relating to activities conducted both in the classroom and in outdoor spaces. According to the literature on technology-mediated learning, digital tools can support knowledge construction processes by promoting the sharing of information, peer collaboration and metacognitive reflection (Goodyear & Carvalho, 2014). The use of the platform also enabled teachers to monitor students' work and provide feedback on the activities carried out.

Types of teaching activities

The teaching activities designed for the experimental group were structured into different types of learning experiences. Learning stations represented one of the main organisational approaches used in classroom activities. In this model, the learning environment is organised into several work stations, each dedicated to a specific activity or problem to be solved. Students work in small groups and rotate between the different stations, engaging with a variety of tasks. This approach promotes student autonomy and allows for the diversification of teaching activities, adapting them to different learning styles. Outdoor problem-solving activities were designed to stimulate students' reasoning through the analysis of real situations in natural or urban environments. Students were required to observe the context, gather information and collaborate in developing possible solutions to the proposed problems. Collaborative digital projects involved students in the creation of shared digital products, such as presentations, concept maps or short reports on the activities carried out. This type of activity fostered the development of digital skills and encouraged peer collaboration. Finally, interdisciplinary workshops integrated content from different school subjects, such as science, geography and Italian language. Through practical and collaborative activities, students had the opportunity to connect knowledge from different domains, developing a more integrated understanding of subject content.

Control group

Alongside the intervention carried out with the experimental group, students in the control group continued to follow the standard school curriculum, undertaking learning activities primarily within the traditional classroom. The activities were based on teaching methods commonly used in the school, including frontal instruction, individual exercises and group work conducted within the classroom setting. The presence of the control group made it possible to compare the results of students who participated in the intervention with those of students who followed the traditional educational pathway, thereby allowing for a more precise evaluation of the effects of the activities carried out in extended learning environments.

6. Results

The analysis of the data allowed for the examination of the effects of the intervention across cognitive, motivational, and socio-relational dimensions. In line with the mixed-methods design, results are presented by distinguishing between quantitative findings and qualitative insights.

For the quantitative analysis, repeated-measures ANOVAs were conducted with group (experimental vs. control) as a between-subjects factor and time (pre-test vs. post-test) as a within-subjects factor. Effect sizes are reported using partial eta squared (η^2). For subgroup analyses (SEN/SpLD) and social skills variables, t-tests were conducted with Cohen's d as effect size. The significance level was set at $p < .05$.

6.1. Quantitative results

Cognitive functions

The analysis revealed significant group × time interaction effects for all executive function measures (Table 1), indicating greater improvements in the experimental group compared to the control group.

Table 1. Cognitive functions.

Variable	Group	Pre-test (A ± DS)	Post-test (A ± DS)	Δ (%)	F(1,118)	p-value	η 2
Selective Attention	Exp.	42.3 ± 6.1	48.2 ± 5.4	+14%	12.45	<.001	.095
	Cont.	41.8 ± 6.3	43.1 ± 6.0	+3%			
Working Memory	Exp.	7.8 ± 1.2	8.7 ± 1.1	+11%	9.32	.003	.073
	Cont.	7.7 ± 1.3	7.9 ± 1.2	+2%			
Cognitive Flexibility	Exp.	35.6 ± 5.8	40.2 ± 5.1	+13%	10.88	.001	.084
	Cont.	35.1 ± 5.9	36.5 ± 5.6	+4%			

Selective attention showed a significant increase in the experimental group ($\Delta = +14\%$) compared to the control group ($\Delta = +3\%$), with a moderate effect size ($F(1,118) = 12.45$, $p < .001$, $\eta^2 = .095$).

Similarly, working memory improved significantly in the experimental group ($\Delta = +11\%$) relative to the control group ($\Delta = +2\%$), with a moderate effect ($F(1,118) = 9.32$, $p = .003$, $\eta^2 = .073$).

Cognitive flexibility also showed a significant group × time interaction, with greater gains in the experimental group ($\Delta = +13\%$) compared to the control group ($\Delta = +4\%$) ($F(1,118) = 10.88$, $p = .001$, $\eta^2 = .084$).

Overall, these results indicate that participation in hybrid learning environments is associated with moderate improvements in executive functions, particularly in attentional control and cognitive flexibility.

Academic motivation

Students in the experimental group showed a notable increase in academic motivation and engagement, with an overall improvement of approximately 18%, compared to minimal changes in the control group.

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A repeated-measures ANOVA showed a significant group × time interaction ($F(1,118) = 7.84$, $p = .006$, $\eta^2 = .062$), indicating that the increase in motivation was significantly greater in the experimental group.

The effect size was in the moderate range ($\eta^2 = .062$), indicating a meaningful impact of the intervention on students' engagement.

This pattern suggests that participation in hybrid and diversified learning environments is associated with higher levels of engagement in school activities

Social skills

Significant differences emerged between groups across all dimensions of social skills (Table 2). Independent-sample t-tests were conducted on gain scores (post–pre differences) to compare improvements between the experimental and control groups.

Table 2. Social skills

Variable	Group	Pre-test (A ± DS)	Post-test (A ± DS)	Δ (%)	t(118)	p-value	d (Cohen)
Cooperation	Exp.	3.2 ± 0.5	3.8 ± 0.4	+20%	4.21	<.001	0.76
	Cont.	3.1 ± 0.6	3.2 ± 0.5	+3%			
Communication	Exp.	3.3 ± 0.6	3.8 ± 0.5	+15%	3.87	<.001	0.70
	Cont.	3.2 ± 0.6	3.3 ± 0.5	+3%			
Collaboration	Exp.	3.1 ± 0.5	3.6 ± 0.4	+17%	4.05	<.001	0.73
	Cont.	3.0 ± 0.5	3.2 ± 0.5	+4%			

Cooperation increased substantially in the experimental group (Δ = +20%; d = 0.76), compared to marginal changes in the control group. Communication also improved significantly (Δ = +15%; d = 0.70), as did collaboration (Δ = +17%; d = 0.73).

The effect sizes ranged from medium to large, indicating a robust impact of the intervention on students' social functioning. These findings suggest that hybrid learning environments are associated with enhanced peer interaction and collaborative behaviours.

Independent-sample t-tests confirmed that post-test differences between the experimental and control groups were statistically significant across all dimensions ($p < .001$).

SEN/SpLD subgroup

Table 3. SEN/SpLD subgroup

Variable	Group	Pre-test (A ± DS)	Post-test (A ± DS)	Δ (%)	t-test	p-value	d
Participation	Exp.	2.9 ± 0.6	3.6 ± 0.5	+24%	3.92	<.001	0.80
	Cont.	2.8 ± 0.6	3.0 ± 0.5	+7%			
Integration	Exp.	3.0 ± 0.5	3.6 ± 0.4	+21%	3.45	.001	0.72
	Cont.	2.9 ± 0.5	3.1 ± 0.5	+6%			
Self esteem	Exp.	3.1 ± 0.6	3.7 ± 0.5	+18%	3.11	.002	0.65
	Cont.	3.0 ± 0.6	3.2 ± 0.5	+6%			

The analysis of the SEN/SpLD subgroup (Table 3) revealed significant improvements across all variables considered.

Participation showed the largest increase ($\Delta = +24\%$; $d = 0.80$), followed by social integration ($\Delta = +21\%$; $d = 0.72$) and self-esteem ($\Delta = +18\%$; $d = 0.65$).

Effect sizes were in the medium-to-large range, suggesting that the intervention had a meaningful impact on this subgroup.

Independent-sample t-tests conducted on gain scores confirmed that improvements in the experimental group were significantly greater than those observed in the control group ($p < .01$), reinforcing the robustness of the intervention effects for this subgroup.

These findings indicate that extended learning environments may support increased engagement and inclusion among students with diverse educational needs.

Overall, the pattern of results consistently indicates that the experimental group outperformed the control group across cognitive, motivational, and socio-relational dimensions, with effect sizes ranging from moderate to large. These findings suggest a robust association between participation in extended learning environments and improvements in key educational outcomes.

These patterns suggest a consistent effect of the intervention across multiple domains, supporting the interpretation of extended learning environments as integrated socio-cognitive systems rather than isolated instructional conditions.

6.2 Qualitative results

Qualitative data were analysed using thematic analysis (Braun & Clarke, 2006), identifying three main themes. The qualitative dataset included multiple teacher interviews and student focus groups, providing a diversified perspective on the educational dynamics observed during the intervention.

Main themes:

1. Increased student engagement
   Students in the experimental group showed higher levels of active participation and interest in learning activities. Teachers reported that the use of multiple environments contributed to increased curiosity and sustained attention.
2. Transformation of collaborative dynamics
   Observations indicated more frequent and spontaneous forms of peer collaboration, including mutual support and shared problem-solving strategies.
3. Positive perception of learning environments
   Students expressed a positive evaluation of hybrid learning environments, particularly appreciating outdoor activities, group work, and the use of digital tools.

Data triangulation was employed to enhance the credibility and validity of qualitative findings.

Overall, qualitative findings are consistent with quantitative results, suggesting that extended learning environments influence not only measurable outcomes but also students' subjective experience of learning.

7. Discussion

The findings of the present study support the interpretation of extended learning environments as active components of educational cognitive systems rather than as mere contexts in which learning occurs. In line with the perspectives of the extended mind (Clark & Chalmers, 1998) and distributed cognition (Hutchins, 1995), the results suggest that physical and digital environments participate directly in shaping cognitive and social practices, contributing to the organisation and regulation of learning processes.

From a systemic perspective, the differences observed between the experimental and control groups—particularly in executive functions, academic motivation, and social skills—can be interpreted as the outcome of distinct configurations of relational systems. In particular, extended learning environments, characterised by a greater diversity of spaces, tools, and interactional opportunities, appear to increase the density of feedback processes within the system. This, in turn, supports cognitive flexibility, adaptive behaviour, and the reorganisation of learning strategies. Such findings are consistent with ecological approaches to cognition, according to which learning emerges from recursive interactions between agents and environments (Barron, 2006; Wheaton et al, 2024). This interpretation is supported by the observed improvements in selective attention, working memory, and cognitive flexibility, which appear particularly sensitive to the variability and richness of hybrid learning environments.

A particularly useful interpretive lens is offered by the ecological epistemology of Gregory Bateson (1972), which conceptualises the mind as a system of differences organised through feedback loops. Within this framework, learning can be understood as a transformation of relational patterns rather than as the internal acquisition of discrete contents. The environments analysed in this study can thus be interpreted as systems in which cognitive processes are continuously reorganised through recursive interactions among students, teachers, artefacts, and spaces.

From this perspective, the mind does not reside exclusively in the individual or in the environment, but in the system of relationships that connects them. The hybrid environments examined in this study can therefore be conceptualised as *cognitive ecologies*, in which learning processes emerge from distributed and co-regulated dynamics. These findings extend previous research by providing empirical support for the interpretation of learning environments as functional units of cognitive systems rather than as external supports (Goodyear & Carvalho, 2014).

Importantly, this interpretation allows the results to be understood not only in terms of the effectiveness of extended environments, but also as evidence of a structural transformation in the nature of educational systems. The data suggest that schools can be increasingly conceptualised as distributed cognitive systems, in which environments, technologies, and social practices co-constitute a single operational ecology. In this sense, hybrid learning environments do not simply facilitate learning; they structure it, influencing how students perceive, process, and reorganise information.

The results relating to student participation and collaboration further support this interpretation. The increased levels of engagement observed in the experimental group are consistent with the literature on collaborative learning (Dillenbourg, 1999), highlighting the role of socio-material configurations in enabling shared knowledge construction. This is also reflected in the significant increase in academic motivation observed in the experimental group, suggesting that diversified and participatory environments may enhance students' intrinsic engagement with learning activities. The organisation of environments—flexible classrooms, outdoor spaces, and digital platforms—appears to play a key role in shaping interactional patterns and participation structures, confirming the importance of design in educational processes (Carvalho & Yeoman, 2018).

Particularly relevant are the findings concerning students with SEN and SpLD, who showed statistically significant improvements in participation, social integration, and self-efficacy, with medium-to-large effect sizes. These results suggest that diversified and flexible environments can reduce structural barriers typical of traditional classroom settings, supporting more inclusive forms of participation. In line with inclusive education research (Florian & Black-Hawkins, 2011; Basister et al., 2025), extended learning environments may therefore function as enabling systems that expand access to learning opportunities.

Finally, the increasing integration of digital technologies—and, more recently, artificial intelligence—introduces an additional layer of complexity in the interpretation of these findings. Digital environments are no longer limited to supporting learning activities but increasingly participate in organising information, structuring tasks, and guiding decision-making processes. Although not directly tested in this study, these dynamics suggest that future configurations of extended learning environments may increasingly integrate AI-based systems as active components in the regulation of learning processes. In this sense, technological systems can be interpreted as *agential components* of educational ecosystems, capable of influencing cognitive processes through adaptive and anticipatory mechanisms (Holmes et al., 2022; Luckin et al., 2016).

This perspective raises a critical issue that extends beyond the effectiveness of learning environments: the question of governance. If learning emerges from distributed systems involving human and technological agents, then the design and regulation of these systems become central to educational practice. The findings of this study thus suggest that understanding how to configure, guide, and govern extended learning environments represents a key challenge for contemporary pedagogy in the design of sustainable and intelligent educational ecosystems.

8. Conclusion

The present study highlights how the design of extended educational ecosystems can represent an effective strategy for promoting more participatory, inclusive, and cognitively rich forms of learning. The integration of physical spaces, outdoor environments, and digital tools appears to create conditions in which students are more actively engaged and able to develop cognitive and social competences through experiences distributed across multiple contexts.

Empirical findings showed consistent improvements in executive functions, academic motivation, and social skills among students involved in the hybrid learning environment, with additional positive effects observed for students with SEN and SpLD in terms of participation, social integration, and self-efficacy. These results reinforce the interpretation of learning environments as active components of cognitive and relational systems.

More broadly, the findings support a shift in how learning itself is conceptualised. Hybrid learning environments do not simply provide alternative settings for educational activities; they contribute to redefining cognitive processes as distributed, relational, and system-based phenomena. In line with situated and distributed learning theories (Lave & Wenger, 1991; Hutchins, 1995), learning emerges from the interaction between individuals, tools, and environments, rather than being confined within the boundaries of the individual mind.

From this perspective, educational spaces can be understood as constitutive elements of cognitive systems. The school that emerges from this study is not a closed institution, but an open and dynamic ecosystem in which the boundaries between classroom, natural environments, and digital spaces become increasingly permeable. This configuration allows for the integration of formal, informal, and non-formal learning experiences, supporting more flexible and inclusive educational pathways.

The inclusive potential of extended learning environments is particularly relevant. The improvements observed among students with SEN and SpLD suggest that diversified and flexible educational settings can reduce structural barriers and expand opportunities for meaningful participation, contributing to more equitable learning processes.

At the same time, the growing integration of advanced digital technologies and artificial intelligence further extends the concept of learning environments as socio-technical systems. Cognitive processes increasingly emerge from interactions between human actors and artificial agents, raising critical questions not only about effectiveness but also about the governance of these ecosystems (Holmes et al., 2022). Designing educational environments therefore implies taking responsibility for how these systems are structured, regulated, and oriented.

Rethinking school as an extended cognitive ecosystem means recognising that the design of spaces, technologies, and social practices is inseparable from the design of cognitive processes themselves. In this sense, educational innovation increasingly depends on the capacity to intentionally configure complex, hybrid, and evolving systems.

Future research should further investigate the long-term effects of extended learning environments and explore how educational institutions can develop sustainable and scalable models for the design and governance of hybrid ecosystems. Advancing this line of inquiry will be essential for understanding how learning develops within increasingly complex, interconnected, and intelligent educational systems.

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