Journal of Inclusive Methodology and Technology in Learning and Teaching
ISSN 2785-5104
Anno 6 n. 1sup (2026)

EDIZIONI UNIVERSITARIE ROMANE
editoria scientifica dal 1952

Extended learning and agent-based artificial intelligence in networked educational ecosystems: a qualitative and quantitative study in lower secondary schools

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Abstract The aim of this study is to empirically investigate the role of agentic artificial intelligence in extended learning processes within networked educational ecosystems. Building on Gregory Bateson's perspectives of the extended mind and the ecology of the mind, the study investigates how AI tools can influence cognitive agency, decision-making processes and learning dynamics in a sample of students attending lower secondary school in the municipality of Santa Maria Capua Vetere, in the province of Caserta. The study was conducted using a mixed-methods (qualitative-quantitative) approach, employing tools validated by the international literature to measure both cognitive and metacognitive variables and subjective representations of learning. The results highlight a significant transformation of distributed cognitive processes and raise important questions for educational governance in human–artificial hybrid environments.

Keywords: artificial intelligence, extended mind, teaching practices, secondary school

1. Introduction

In recent years, the extended mind paradigm has radically transformed our understanding of cognition and learning, challenging the individualistic view of the mind. According to this perspective, cognition emerges from the interaction between the individual, artefacts, environments and social relationships. This approach has its roots in the work of Gregory Bateson, who defines the mind as a system of relationships based on feedback loops and meaningful differences (Bateson, 2000). His famous definition of information as 'a difference that makes a difference' helps us understand the relational and systemic nature of cognitive processes, anticipating subsequent developments in distributed cognitive science.

Bateson's contribution forms part of a broader theoretical lineage that includes second-order cybernetics (von Foerster, 2003), systems theory (Capra & Luisi, 2014) and ecological perspectives on the mind (Heft, 2020). In particular, the notion of affordance has redefined the relationship between organism and environment, highlighting how opportunities for action emerge from the interaction between environmental characteristics and the subject's perceptual capacities, profoundly influencing theories of situated learning (Wenger-Trayner & Wenger-Trayner, 2020).

In line with these perspectives, the extended mind paradigm has been developed within 4E (embodied, embedded, extended, enactive) theories of cognition (Newen, De Bruin & Gallagher, 2018). According to these approaches, digital tools and information environments can be considered an integral part of the cognitive system when they perform a stable function in mental processes. This strand has given rise to interdisciplinary developments in epistemology (Carter, 2018) and in the educational sciences (Luckin, 2018; Dede, 2020). In parallel, the theory of distributed cognition has been extended in studies of complex socio-technical systems (Giere, 2019), highlighting how cognitive processes emerge from the interaction between people, artefacts and contexts, including within the context of technology-mediated collaborative learning (Hmelo-Silver & Jeong, 2022).

In the educational context, these theoretical shifts have called into question the traditional, individualistic model of learning, in favour of participatory and systemic models. Learning is thus understood as an emergent, situated and distributed process, in which students, teachers, tools and environments co-construct meaning within complex ecosystems (Engeström, 2017).

However, the spread of agentic artificial intelligence systems introduces a qualitative discontinuity compared to previous forms of cognitive extension. Today, we are witnessing the development of systems capable of learning, generating content and interacting autonomously with users. Contemporary AI, particularly that based on generative models, actively participates in the construction of cognitive processes, introducing new forms of distributed agency (Watson, Mökander & Floridi, 2025). In this sense, AI can be interpreted as an epistemic agent that contributes to the production of knowledge (Bender et al., 2021).

In the field of education, this transformation raises significant epistemological and pedagogical questions. Recent studies highlight, on the one hand, the potential of AI in terms of personalisation and adaptive feedback (Zawacki-Richter et al., 2019), and on the other, critical issues related to transparency, bias and cognitive dependence (Selwyn, 2021). From a Batesonian perspective, artificial intelligence can be

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interpreted as a new element within complex cybernetic systems, capable of redefining the relational patterns of cognition and transforming the ecology of the mind.

This transformation is particularly evident in educational contexts, where interaction with AI systems alters the processes of knowledge construction and redefines cognitive agency, introducing forms of co-agency between humans and artificial systems (Long & Magerko, 2020). This raises a central question: 'Where is the mind today?'. The boundaries of cognition appear increasingly dynamic and negotiated within complex socio-technical systems. From this perspective, the issue of educational governance also emerges. If the mind is distributed, so too is the responsibility for learning. This implies a redefinition of roles within the education system, conceived as an open ecosystem and a network of relationships between actors, technologies and institutions (Biesta, 2021). Furthermore, it is essential to develop critical skills in the use of AI, recognised as a central element of contemporary digital citizenship (Selwyn, 2021; UNESCO, 2023). Despite the growing theoretical and practical focus on artificial intelligence in education, there remains limited empirical evidence on how agentic AI actually contributes to the reconfiguration of cognitive agency in school contexts, particularly in lower secondary schools. In this regard, it is necessary to investigate how such technologies influence metacognitive, decision-making and learning processes in real educational settings.

In light of these considerations, this study lies at the intersection of extended mind theory, the ecology of the mind, and empirical research on AI in education, and is situated within the framework of extended learning in networked educational ecosystems. From this perspective, the research contributes to the contemporary debate on where the mind is situated within hybrid socio-technical systems, assuming that cognition emerges from dynamic networks of interaction between human and artificial agents.

The specific contribution of this study lies in providing empirical evidence on the role of agentic artificial intelligence in reconfiguring cognitive agency within networked educational ecosystems, integrating theoretical perspectives of the extended mind and distributed cognition with data from real-world school contexts.

In conclusion, the introduction of agentic artificial intelligence into educational contexts represents a paradigm shift that requires an interdisciplinary approach to understand how cognition, learning and agency are redefined in hybrid environments.

2. Aim of the research

The aim of this study is to analyse the role of agent-based artificial intelligence in learning processes, with a particular focus on its impact on metacognition and the ways in which students regulate and reflect on their own learning. In line with recent literature, which highlights how AI systems can influence cognitive strategies, self-regulation and metacognitive awareness, the study aims to explore how such technologies can redefine learning processes in advanced digital environments (Luckin, 2018).

A second objective is to analyse the transformations of cognitive agency in hybrid learning environments, where the interaction between human and artificial agents gives rise to forms of co-agency. Recent studies highlight how the use of artificial intelligence can both enhance students' autonomy and, in some cases, reduce cognitive effort and self-regulation capacity, underscoring the ambivalent nature of such technologies (Long & Magerko, 2020; Selwyn, 2021).

The research also aims to investigate students' subjective perceptions regarding the distribution of the mind between human and artificial agents, considering how they define the role of AI in their own cognitive and decision-making processes.

Finally, the study aims to contribute to the discussion on educational governance in extended learning environments, where the introduction of artificial intelligence requires new forms of pedagogical design and ethical regulation. Recent literature indeed highlights the need to develop models of responsible educational AI, capable of integrating cognitive, social and ethical dimensions into the design of learning systems (Antoninis, M. et al., 2023)

3. Methods

3.1. Research framework

This study adopted a mixed-methods approach, specifically a convergent-parallel design (Creswell & Creswell, J. D., 2017), which is useful for investigating complex, multi-level phenomena such as learning in socio-technical ecosystems mediated by artificial intelligence. This methodological choice allows for the integration of different dimensions of the phenomenon under investigation: on the one hand, the measurement of cognitive, metacognitive and motivational variables using standardised quantitative tools; on the other, the exploration of subjective representations, situated practices and emerging agency dynamics through qualitative data. This methodological approach involves the use of both quantitative and qualitative data, their separate analysis, and subsequent interpretative integration. This framework allows for the comparison and triangulation of results, the strengthening of conclusions, and the identification of any convergences or discrepancies between the different data sources. In particular, the quantitative data enabled us to identify variations in levels of metacognition, cognitive load and learning strategies, whilst the qualitative data provided a deeper understanding of the ways in which students perceive and negotiate their interaction with AI systems. From an epistemological perspective, the use of a mixed-methods approach is consistent with the theoretical framework of the extended mind and distributed cognition, which calls for the use of tools capable of capturing the complexity of learning systems. The integration of quantitative and qualitative data reflects, in fact, the hybrid and relational nature of the phenomena studied, avoiding both positivist and interpretative forms of reductionism. The study has certain methodological limitations, including the non-randomised nature of the sample and the specific nature of the school context in which it was conducted, which may affect the generalisability of the findings. These factors were, however, taken into account during the design and data analysis phases, through the use of triangulation and interpretative contextualisation. The study has certain methodological limitations, including the non-randomised nature of the sample and the specific nature of the school context in which it was conducted, which may affect the generalisability of the results. These factors were, however, taken into account during the design and data analysis phases, through the use of triangulation and interpretative contextualisation strategies.

3.2. Context and sample

The study was conducted at a lower secondary school located in the municipality of Santa Maria Capua Vetere, in the province of Caserta, chosen because of the presence of teaching practices already geared towards the integration of digital technologies and the teaching staff's willingness to participate in a structured experimental programme. The school context exhibits heterogeneous socio-economic characteristics, ensuring greater representativeness of the sample in relation to the lower secondary school student population. The sample consists of 124 students (mean age: 12.4 years; standard deviation: 0.7), from Year 7 and Year 8. This age group was selected because the students possess sufficiently developed cognitive and metacognitive skills to interact meaningfully with artificial intelligence systems, yet are still in the process of consolidating their learning strategies, making them particularly sensitive to the transformations brought about by hybrid cognitive environments. The definition of the sample was guided by precise methodological criteria. In particular, students capable of actively participating in the activities were selected in order to reduce the presence of biases that might have compromised the

interpretation of the data.
The students were selected on the basis of specific inclusion criteria:

- regular attendance at school, in order to ensure continuity in participation in the activities set out in the research protocol;
- active participation in educational programmes involving the use of digital technologies, a necessary condition for ensuring familiarity with digital environments;
- possession of basic digital skills (e.g. use of educational platforms, digital writing tools and web browsing), verified through a preliminary test, to enable effective interaction with AI systems;
- informed consent from families and assent from students, in accordance with current ethical regulations in the field of educational research;
- no significant language barriers that could compromise understanding of the activities and assessment tools;
- willingness to participate in qualitative activities (interviews, focus groups, reflective diaries), an essential element for data integration.

At the same time, exclusion criteria were defined to ensure the reliability and consistency of the data collected:

- prolonged absences (exceeding 25% of scheduled activities), which would have compromised full participation in the programme and the comparability of pre- and post-data;
- lack of parental consent to participate or withdrawal of consent during the study;
- significant difficulties in using digital tools identified during the preliminary phase, such as to prevent independent participation in AI-based activities;
- incomplete participation in data collection phases (e.g. failure to complete questionnaires or failure to participate in qualitative surveys);
- contingent circumstances (transfer to another institution, prolonged health issues) that prevented continued participation.

The inclusion and exclusion criteria were clearly specified in order to ensure methodological transparency and contextualisation of the study results, highlighting their limitations and conditions for generalisability.

3.3. Quantitative tools

For the analysis of quantitative data, and more specifically for the assessment of cognitive and metacognitive variables, validated instruments widely recognised in the literature were used:

- Metacognitive Awareness Inventory (MAI), adapted for the Italian school population, to measure metacognitive awareness;
- Motivated Strategies for Learning Questionnaire (MSLQ), to analyse learning strategies and motivation;
- Cognitive Load Scale (CLS), to assess the perceived cognitive load during interaction with AI systems.

In addition, a structured problem-solving test, designed in accordance with OECD-PISA standards, was administered to measure reasoning skills in AI-mediated contexts.

3.4. Quanlitative tools

With regard to the qualitative analysis, the following methods were used:

- semi-structured interviews, to explore students' perceptions of the role of AI in cognitive processes;
- focus groups, designed to investigate collaborative dynamics and perceptions of distributed cognition;
- reflective journals, in which students documented their learning experiences with AI.

The qualitative analysis was conducted using a thematic approach, in accordance with the guidelines set out by Braun and Clarke.

3.5. Activities

The educational intervention was designed in line with the theoretical framework of the extended mind and distributed cognition, viewing learning as a dynamic process that emerges from the interaction between individuals, tools and contexts. In line with the literature on the use of mixed-methods approaches in education (Creswell, J. W., & Creswell, J. D. 2017; Johnson & Christensen, 2024), the study was structured in three sequential phases, each of which addressed specific methodological and theoretical requirements. In the first phase, the students' cognitive, metacognitive and motivational skills were assessed. This phase was crucial in establishing a baseline against which to evaluate any changes following the intervention. The administration of standardised instruments, such as the Metacognitive Awareness Inventory and the Motivated Strategies for Learning Questionnaire, was accompanied by structured problem-solving tasks, in order to identify the cognitive strategies actually used by the students (Brandmo, C., Panadero, E., & Hopfenbeck, T. N.; 2020). The baseline assessment was not designed as a moment of metacognitive activation. Recent literature highlights that initial awareness of one's own learning strategies is fundamental to the development of self-regulatory skills (Panadero, 2017; Greene, J. A., Copeland, D. Z., Deekens, V. M., & Freed, R. 2018). Furthermore, from a distributed cognition perspective, the baseline assessment allowed us to observe how students organise their cognitive processes without AI systems, providing a point of comparison for analysing the subsequent restructuring of these processes in hybrid environments.

The second phase formed the core of the educational intervention and took the form of a six-week learning programme, designed in accordance with the principles of situated learning and learning by design (Wenger-Trayner, E., Wenger, E., & Wenger-Trayner, B.; 2020; Dede, C., & Richards, J.; 2020). The students undertook complex problem-solving and argumentative writing activities, facilitated by the use of generative artificial intelligence systems. The problem-solving activities were structured around authentic, contextualised tasks. The students worked on open-ended problems that required the analysis of information, the formulation of hypotheses and the evaluation of alternative solutions. In this way, AI was used as a cognitive aid, capable of providing suggestions, generating alternatives and facilitating the exploration of scenarios. This approach ties in with recent studies on digital 'cognitive tools' and AI as a learning aid (Luckin, 2018). In parallel, during argumentative writing activities, students produced complex texts, supported by interaction with AI systems capable of generating drafts, suggesting argumentative structures and providing linguistic feedback. Argumentative writing activities were included given their relevance to the development of critical and reflective thinking (Kuhn D., 2019). Recent studies highlight how writing supported by digital technologies and AI can facilitate revision processes and metacognitive awareness (Zhai et al., 2021). In this phase, the educational context was conceived as a hybrid learning environment in which AI acts as a cognitive partner, contributing to the co-construction of knowledge (Holmes & Tuomi, 2022). In line with contemporary theories of extended cognition and 4E, interaction with AI was designed to be stable and functionally integrated into learning processes (Newen et al., 2018). It was essential to ensure a balance between support and autonomy. Recent literature on self-regulation highlights the risk that excessive technological support may reduce students' cognitive engagement (Hadwin, Järvelä & Miller, 2017; Azevedo & Gašević, 2019). For this reason, the activities were structured to require a critical evaluation of the responses generated by the AI, thereby promoting metacognitive monitoring processes (Panadero, 2017).

In parallel with the qualitative analysis, qualitative data were also collected during the intervention through reflective journals and classroom observations, with the aim of demonstrating how students and AI systems interact. This approach draws on

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contemporary research on situated learning and contextualised educational practices (Fischer et al., 2022).

The third phase involved the collection of post-intervention data, using the same tools administered in the baseline phase, in order to compare and evaluate the changes that had taken place. This phase also included semi-structured interviews and focus groups, in order to explore students' perceptions of their experience in greater depth. The post-intervention assessment aimed not only to measure outcomes but also to understand the processes through which these outcomes developed. In line with the literature on mixed methods (Creswell & Creswell, J. D., 2017), the integration of quantitative and qualitative data allowed for a more nuanced interpretation of the results, highlighting not only 'whether' changes had occurred, but also 'how' and 'why'. In particular, the interviews explored the perception of AI as a cognitive agent, the distribution of agency in learning processes, and the degree of trust in the generated responses. Through the focus groups, it was possible to analyse the emerging social and collaborative dynamics, in line with recent studies on computer-supported collaborative learning (Hmelo-Silver, C. E., & Jeong, H., 2022). The adoption of this procedure reflects a conception of educational intervention as a situated and complex experience, designed to be as close as possible to the reality of school contexts, whilst maintaining adequate control over variables. This methodological choice is consistent with the study's objective of investigating learning in real ecosystems, avoiding excessive simplifications that could compromise the validity of the results.

4. Results

4.1. Quantitative results

The quantitative analysis was conducted using repeated-measures ANOVA to compare pre- and post-intervention scores across the various variables under investigation. The data analysis reveals both positive effects of integrating artificial intelligence into learning processes and certain challenges associated with the restructuring of cognitive agency.

Table 1. MAI and MSLQ pre-post results

Variable	Pre-test (A)	Post-test (A)	F(1,123)	p	ηp^2
Metacognitive awareness (MAI)	63,4	71,8	18,72	< .01	.13
Self-regulation (MSLQ)	4,1	4,8	12,55	< .01	.09

With regard to metacognitive awareness, as measured by the Metacognitive Awareness Inventory (MAI), a statistically significant increase was observed in overall scores (pre-test M = 63.4; post-test M = 71.8; $F(1,123) = 18.72$; $p < .01$; $\eta p^2 = .13$). Analysis of the subscales reveals a particularly marked improvement in the monitoring and evaluation dimensions, whilst the planning dimension shows a more modest increase. This result suggests that interaction with AI systems fosters greater ongoing awareness of cognitive processes, likely due to the dialogic and reflective nature of interaction with the technological artefact. In line with the literature (Azevedo & Cromley, 2004), AI appears to act as a metacognitive scaffold, making explicit processes that often remain implicit.

With regard to learning strategies and motivation, assessed using the Motivated Strategies for Learning Questionnaire (MSLQ), the results show a significant increase in the scales relating to self-regulation (pre-test M = 4.1; post-test M = 4.8 on a 1–7 Likert scale; $F(1,123) = 12.55$; $p < .01$; $\eta p^2 = .09$) and the use of deep cognitive strategies (processing and organisation). There was also a slight increase in intrinsic motivation, although this was not statistically significant ($p = .08$). These data indicate that the use of AI can foster more active engagement in learning processes, supporting practices of reflection and re-elaboration. However, the absence of a significant increase in motivation suggests that the effect of AI lies more at the cognitive and metacognitive level than at the motivational level, confirming the findings of previous studies (Winne & Hadwin, 2008).

With regard to cognitive load, as measured using the Cognitive Load Scale (CLS), there was a significant reduction in the intrinsic cognitive load associated with complex tasks (pre-test M = 5.2; post-test M = 4.3 on a scale of 1–9; $F(1,123) = 15.03$; $p < .01$; $\eta p^2 = .11$), whilst extrinsic cognitive load remains stable. This finding suggests that AI contributes to better management of cognitive resources, likely through the distribution of the load between the student and the technological system. In terms of cognitive load theory (Sweller, 2011), AI appears to function as a complexity-reducing device, allowing students to focus on deeper aspects of the task. However, it is important to emphasise that an excessive reduction in cognitive load could lead to a decrease in cognitive engagement, with possible negative effects on long-term learning.

The results relating to problem solving, assessed through structured tests inspired by the OECD-PISA framework, show a moderate improvement in overall performance (pre-test M = 58.6%; post-test M = 65.2%; $F(1,123) = 9.87$; $p < .05$; $\eta p^2 = .07$). However, a more in-depth analysis reveals a reduction in the variability of the strategies adopted by students. In particular, there is a greater convergence towards solutions suggested or validated by the AI, with a decrease in exploratory and divergent strategies. This phenomenon can be interpreted in the light of the concept of 'automation bias' (Parasuraman & Riley, 1997), namely the tendency to place excessive trust in automated systems, thereby reducing critical control.

A further significant finding concerns decision-making dependence on AI, measured using a specially constructed composite indicator based on the frequency of accepting AI-generated responses without modification. The results show a significant increase in this indicator (pre-test $M = 2.3$; post-test $M = 3.9$ on a scale of 1–5; $F(1,123) = 21.44$; $p < .001$; $\eta p^2 = .15$). This finding highlights a growing cognitive delegation, in which AI is perceived as an authoritative source of decision-making. Whilst this phenomenon may, on the one hand, be interpreted as a sign of effective integration of AI into cognitive processes, on the other it raises critical questions regarding the loss of autonomy and the reduction of critical thinking. Overall, the quantitative results paint an ambivalent picture. On the one hand, the integration of AI into learning processes appears capable of enhancing metacognitive awareness, supporting self-regulation and reducing cognitive load. On the other hand, there are signs of a possible restructuring of cognitive agency, characterised by greater dependence on artificial systems and a reduction in strategic diversity.

These findings are consistent with a distributed cognition perspective: learning cannot be reduced to either the individual or the tool, but emerges from the interaction between the two. However, the quality of this interaction depends on the design conditions and the educational practices adopted. In the absence of adequate mechanisms for critical mediation, there is a risk that the extension of the mind will result in its delegation rather than its enhancement.

4.1. Quanlitative results

The qualitative analysis was conducted using the reflective thematic analysis approach (Braun & Clarke, 2006), with the support of NVivo software (version 14), which was used for the coding, organisation and triangulation of data from semi-structured interviews, focus groups and students' reflective diaries. The analytical process was divided into six stages: familiarisation with the data, generation of initial codes, identification of themes, review of themes, definition and naming of themes, and production of the report.

Through inductive coding, 47 open-ended codes were initially identified, subsequently aggregated into intermediate categories and finally organised into three main thematic clusters. The reliability of the coding was ensured through a double-coding procedure on a 20% subsample of the data, with an inter-coder agreement coefficient (Cohen's Kappa) of 0.82, indicating a high degree of interpretative consistency.

Theme 1: AI as a cognitive partner

The first thematic cluster that emerged concerns the shift in students' perception of artificial intelligence, no longer seen as a mere tool but as a 'cognitive partner'. This theme occurs with high frequency (NVivo coverage: 38% of coded units of meaning) and is characterised by descriptions of interaction with AI in dialogical, collaborative and sometimes almost relational terms.

Students use expressions that suggest a form of co-construction of thought, such as 'it helps me understand better', 'it's as if we were reasoning together' or 'it gives me ideas that I then develop myself'. This type of representation is consistent with the latest perspectives on distributed cognition and co-agency in human–AI systems, which interpret interaction with intelligent technologies as a shared process of knowledge construction (Hollan, Hutchins & Kirsh, 2000; Long & Magerko, 2020), as well as with studies on AI as an advanced cognitive aid in educational contexts (Holmes & Tuomi, 2022). From an interpretative perspective, this finding suggests that interaction with generative AI systems is not experienced as external to the cognitive process, but as an integral part of it. In systemic terms, it can be argued that AI enters the feedback loops that constitute the cognitive system, contributing to the production of new configurations of meaning (Floridi L., 2023). However, this integration is not neutral: it redefines the ways in which students access information and construct knowledge, introducing new forms of epistemic mediation and cognitive dependence (Selwyn, 2021; Bender et al., 2021).

Theme 2: Redefining agency and co-decision-making

The second thematic cluster, accounting for 34% of the coded units, concerns the redefinition of cognitive agency. Focus groups with students reveal a frequent sense of 'co-decision-making', in which the decision-making process is no longer attributable exclusively to the individual, but emerges from interaction with AI.

Expressions such as "we decide together", "I trust what it says but then I choose" or "sometimes I follow what it suggests" highlight a continuous negotiation between autonomy and dependence. This phenomenon can be interpreted in the light of the concept of "shared agency" and the most recent reflections on human–machine co-agency (Long & Magerko, 2020).

The analysis of NVivo nodes shows a strong co-occurrence between codes relating to trust in AI and those relating to decision-making delegation (Pearson's $r = 0.62$), suggesting that the perceived reliability of the system directly influences the degree of cognitive delegation. In some cases, students report a reduction in decision-making effort, relying on AI-generated responses without in-depth processing.

This qualitative finding complements the quantitative results regarding increased decision-making dependence, reinforcing the hypothesis that AI not only supports but also restructures agency processes. From an extended mind perspective, this implies that the unit of analysis for cognitive action is no longer the individual, but the hybrid system comprising the student and technology.

Theme 3: Critical awareness and the risk of cognitive delegation

The third thematic cluster, accounting for 28%, concerns critical awareness in the use of AI. The data reveal differences among students: whilst some demonstrate the ability to evaluate, compare and rework the generated responses, others tend to accept them uncritically.

Students with greater metacognitive awareness employ verification strategies, such as cross-checking with other sources or rephrasing responses, demonstrating an active and reflective approach. Conversely, a significant proportion of the sample exhibits a tendency towards cognitive delegation, expressed in statements such as 'if the AI says so, it must be right' or 'I don't need to check'.

The NVivo analysis highlights that the codes associated with critical evaluation are less frequent and less connected to other nodes, indicating that this theme plays a less central role in students' practices. This finding is consistent with recent literature on the risks of over-reliance on automated systems and on automation bias in digital and educational contexts (Bender et al., 2021; Cummings, 2021; Selwyn, 2021), and underscores the need to develop critical skills when interacting with intelligent systems.

From a theoretical perspective, this theme represents a crucial tension within the extended mind paradigm. Whilst cognitive extension involves the integration of artefacts into mental processes, it also requires the ability to govern such integration. In the absence of critical awareness, extension can turn into a form of dependency, compromising cognitive autonomy.

The integration of qualitative findings, supported by thematic analysis using NVivo, allows us to outline a complex and multifaceted picture. Artificial intelligence proves to be a fully integrated element within students' cognitive systems, capable of transforming learning modes and redefining agency.

The three thematic areas identified are closely interlinked: the perception of AI as a cognitive partner facilitates co-decision-making, which in turn can either foster or hinder the development of critical awareness. In this sense, AI acts as an amplifier of existing cognitive dynamics, bringing into sharper relief both the potential and the vulnerabilities of learning processes.

In conclusion, the qualitative findings confirm and enrich the results of the quantitative analysis, highlighting that learning in AI-mediated environments cannot be understood solely in terms of performance, but requires attention to the profound transformations in students' cognitive practices and representations.

5. Discussion

The findings of the study provide a basis for a detailed examination of the relationship between learning, cognitive agency and artificial intelligence within networked educational environments, both confirming and challenging the theoretical framework of distributed cognition and the extended mind.

Firstly, the presence of quantitative and qualitative data reinforces the hypothesis that artificial intelligence does not merely function as a support tool, but becomes part of students' cognitive processes as an active agent. The significant increase in metacognitive awareness and self-regulation strategies, as measured by the MAI and the MSLQ, finds a qualitative counterpart in the perception of AI as a 'cognitive partner'. This finding suggests that AI is progressively internalised as a functional component of the cognitive system, in line with contemporary perspectives on 4E cognition and the extension of the mind (Newen, De Bruin & Gallagher, 2018; Carter, 2018).

In systemic terms, the results can be interpreted as empirical evidence that the mind is configured as a system of relationships regulated by feedback loops, within which AI represents a new node capable of introducing significant differences. Interaction with generative AI systems in fact modifies patterns of communication and information processing, making the distributed nature of cognition visible. In this sense, the mind does not simply extend outwards, but reconfigures itself through new forms of coupling between human and artificial systems, in line with recent reflections on the informational ecosystem and on AI as an epistemic agent (Floridi, 2023).

However, alongside these elements of cognitive enhancement, a structural tension clearly emerges that runs through the entire body of findings. Whilst AI helps to reduce the cognitive load and support more sophisticated metacognitive processes, it also introduces dynamics of dependency that may undermine students' cognitive autonomy. The reduction in variability in problem-solving strategies, together with the significant increase in the decision-making dependency index, suggests that interaction with AI may foster forms of 'strategic flattening', in which solutions tend to converge towards those suggested by the system.

This dynamic is further confirmed by the qualitative data, in particular by the theme of co-decision-making and the limited prevalence of critical evaluation practices. Analysis using NVivo highlights how trust in AI is closely correlated with the delegation of decision-making, constituting a form of distributed agency in which the human contribution risks being progressively marginalised. In this sense, the findings are consistent with recent literature on the risks of over-reliance on automated systems and on automation bias in digital and educational contexts (Bender et al., 2021; Cummings, 2021; Selwyn, 2021), demonstrating how this phenomenon can directly impact learning processes.

This ambivalence raises a central theoretical question: the extension of the mind is not a neutral process, but depends on design conditions and the practices that govern the interaction between subjects and artefacts. Recent perspectives in extended epistemology highlight how the integration of tools into cognitive processes entails a transformation of epistemic practices, which can be as emancipatory as it is constraining (Carter, 2020; Heersmink, 2020). In the case of AI, this transformation takes on even greater significance, as artefacts do not merely support thought but actively participate in its production.

From this perspective, the study's findings suggest that the question is no longer merely 'where is the mind', but 'who governs the processes through which the mind extends'.

This question takes on crucial importance in contemporary educational contexts, where the design, implementation and use of artificial intelligence systems are the result of technical, pedagogical and political choices. The governance of extended learning concerns not only the organisation of teaching practices, but also involves a reflection on the responsibilities distributed among institutions, teachers, technology designers and students, as well as on the epistemic and ethical logics that guide such systems.

The introduction of AI into educational settings brings the political and ethical dimensions of distributed cognition into sharp focus, placing the issue of governance at the centre. The extended mind thus becomes a matter of collective design and responsibility, requiring reflection on conditions of access, modes of use and educational objectives (Williamson, 2020; UNESCO, 2023).

In the field of pedagogy, this implies a profound reconfiguration of the role of the school. The findings highlight the need to move beyond a conception of the school as a closed system, towards an ecosystemic vision in which learning emerges from networks of relationships between human and non-human actors.

From this perspective, the school functions as an active node within networked educational ecosystems, where knowledge production emerges from interactions distributed across physical, digital and social environments.

Within this framework, the governance of learning cannot be centralised but must be distributed, in line with the distributed nature of the mind.

This reconfiguration requires the development of co-design practices in teaching, in which teachers, students and technologies participate in the construction of learning pathways. Teacher training takes on a crucial role, not only in terms of technical skills, but above all in relation to the ability to orchestrate hybrid learning environments and to promote critical awareness in the use of AI. In line with recent literature, education on artificial intelligence must include a reflective and critical dimension, aimed at understanding the epistemic and ethical implications of these technologies (Selwyn, 2021; Holmes et al., 2022).

The findings suggest the need to design learning environments in which artificial intelligence is integrated as a reflective rather than a substitute tool, promoting practices of critical evaluation and processes of co-construction of knowledge. From this perspective, the use of AI should be accompanied by pedagogical approaches geared towards the development of cognitive autonomy, capable of supporting metacognitive monitoring and preventing forms of unconscious decision-making delegation.

A further element that emerged concerns the need to develop pedagogical tools capable of countering cognitive delegation and supporting student autonomy. The data suggest that AI can be a powerful learning tool only if embedded within practices that critically regulate its use. This implies, for example, the design of activities that require the evaluation of generated responses, the comparison of sources, and the independent reworking of information. In the absence of such mechanisms, there is a risk that the extension of the mind will result in its ungoverned externalisation.

From a theoretical perspective, the study contributes to updating the extended mind paradigm, highlighting the need to consider not only the functional integration of artefacts, but also their agency and their role in decision-making processes. AI introduces a form of extension that is no longer merely instrumental, but organisational and institutional, redefining the boundaries of the cognitive system. In this sense, the contemporary extended mind can be described as a co-evolutionary mind, which develops in interaction with intelligent environments capable of learning and adapting.

Finally, it is worth considering the limitations of the study. Although the sample size is adequate for an exploratory analysis, it does not allow for broad generalisation of the results. Furthermore, the relatively short duration of the intervention limits the possibility of observing long-term effects, particularly with regard to the development of critical awareness. Furthermore, the exclusion of students with special educational needs who are not supported by adequate resources represents a limitation in terms of inclusivity, which future research will need to address.

In light of these limitations, several directions for future research emerge. Firstly, it would be advisable to develop longitudinal studies that allow for the analysis of the evolution of cognitive agency over time. Secondly, it appears necessary to explore the role of socio-cultural variables in greater depth. Finally, further research could explore instructional design models that integrate AI in a critical and sustainable manner.

In conclusion, the study's findings highlight that artificial intelligence is not merely a new tool for learning, but a transformative element that redefines the very nature of cognition and educational governance. The challenge for contemporary pedagogy is not to limit or passively accept this transformation, but to understand and guide it, developing practices and models capable of harnessing the potential of AI without compromising the autonomy and responsibility of those involved.

6. Conclusion

This research offers an empirical and theoretical contribution to our understanding of the transformations taking place in learning processes within educational ecosystems that are increasingly characterised by the presence of agentic artificial intelligence (Holmes et al., 2023).

In particular, the specific contribution of the study lies in having demonstrated, through a mixed-methods design, how agentic artificial intelligence does not merely support learning processes, but contributes to restructuring cognitive agency within socio-technical educational systems, whilst highlighting both the potential and the critical issues of such transformations.

The results highlight how AI does not simply represent an incremental technological innovation, but an element capable of profoundly redefining the very structure of cognition, shaping new forms of hybrid extended mind, in which human and artificial entities co-construct knowledge processes (Floridi, 2023).

In particular, the integration of quantitative and qualitative data has shown that interaction with AI systems can support the development of metacognitive awareness, promote self-regulated learning and reduce the cognitive load in complex tasks (Azevedo & Gašević, 2019). This evidence suggests that AI, when properly integrated into educational contexts, can function as a powerful cognitive mediation tool, capable of amplifying students' abilities and making highly complex tasks more accessible (Zawacki-Richter et al., 2019).

However, alongside this potential, significant concerns are emerging. The tendency towards cognitive delegation, the reduction in strategic variability in problem-solving processes, and the limited prevalence of critical evaluation practices suggest that the extension of the mind through AI also entails significant risks to cognitive autonomy (Selwyn, 2021). In this sense, AI does not merely enhance learning processes, but restructures them, introducing new forms of dependency and redefining the boundaries of agency (Floridi, 2023; Bender et al., 2021).

This ambivalence lies at the heart of contemporary pedagogical reflection. The challenge is not to reject the extension of the mind, nor to celebrate it uncritically, but to govern it (Selwyn, 2021). Governing the extension means designing conditions in which the integration of human and artificial elements takes place in a conscious, critical manner, geared towards the development of students' cognitive abilities.

From this perspective, the concept of the extended mind must be further developed from a systemic and political standpoint (Floridi, 2023). It is not merely a matter of recognising that the mind extends into artefacts, but of questioning who designs, controls and directs such systems, and the epistemic and ethical principles that guide their operation (Williamson & Eynon, 2020). Artificial intelligence, in fact, introduces a dimension of opacity and autonomy that makes reflection on educational governance even more urgent (Bender et al., 2021).

From this perspective, schools are called upon to redefine their role, positioning themselves as nodes within complex educational ecosystems where technological, social and cultural dimensions intertwine. This implies a transformation of teaching and professional practices: teachers become designers of learning environments, capable of orchestrating the interaction between students and AI systems (Holmes et al., 2023), whilst students must develop advanced forms of critical literacy, understanding not only how to use the tools but also how to assess their cognitive and ethical implications (Ng et al., 2021).

A further contribution of the study concerns the need to rethink the assessment of learning. In a context of distributed cognition, it is no longer sufficient to assess individual performance in isolation; instead, one must consider the processes, interactions and support networks that contribute to the construction of knowledge (Fawns, 2022).

From a research perspective, the findings open up several avenues for further investigation, including the study of the conditions that foster a balanced development of cognitive agency in the presence of AI and the analysis of the individual and socio-cultural differences that influence these processes (Holmes et al., 2023).

In conclusion, the question that guided this research – 'where is the mind today?' – finds an answer that is both theoretical and empirical: the mind resides neither exclusively in the subject nor in the tool, but emerges in the relational systems that connect them. From this perspective, this question must be interpreted in relational and systemic terms, considering the mind as an emergent property of constantly evolving networked educational ecosystems.

Understanding, designing and governing these systems is now the central task of education. In a world where cognition is increasingly distributed and mediated by artificial agents, the challenge is not to preserve a supposed purity of the human mind, but to develop forms of collective and hybrid intelligence capable of addressing contemporary complexity in a critical, responsible and sustainable manner (Floridi, 2023).

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