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DANCING WITH SWARMS: ECO-CENTERED PSYCHOLOGICAL FACILITATION AND THE FUTURE OF LEARNING

Abstract. This paper explores the convergence between swarm intelligence principles, stigmergic coordination, and Eco-Centered Psychological Facilitation (ECPF) as a transformative framework for reimagining education and psychology in the posthuman age. Drawing on recent research in collective intelligence, distributed cognition, stigmergic coordination, and AI-mediated learning environments, it argues that psychological and educational facilitation should be reconceptualized as ecological tuning—the artful creation of rhythmic, spatial, and relational conditions that enable emergent self-organization through environmental traces. The concept of stigmergy—coordination through traces left in the environment—provides a concrete mechanism for understanding how collective intelligence emerges in educational settings. Through an integration of insights from complexity science, urban morphogenesis, posthumanist philosophy, and ethical AI frameworks, this study outlines comprehensive design principles for hybrid human-AI learning environments where participants actively "stigmergize" meaning through iterative trace-making. It proposes an ecological ethics of minimal intervention combined with metacommunicative awareness as the foundation for psychological and educational transformation, positioning

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the facilitator as a conductor of temporal rhythms, keeper of stigmergic traces, and cultivator of collective reflexivity. The implications extend beyond traditional pedagogical boundaries, suggesting new possibilities for understanding human development, collective intelligence, and the co-evolution of human and artificial cognitive systems in educational contexts through the lens of stigmergic self-organization.

Keywords: swarm intelligence; Eco-Centered Psychological Facilitation (ECPF); stigmergy; stigmergic coordination; AI in education; distributed cognition; posthumanism; collective intelligence; hybrid learning environments; emergent self-organization; ecological tuning; educational transformation; human-AI collaboration; metacommunication; environmental traces; collective reflexivity.

INTRODUCTION / ВСТУП

Statement of the problem / Постановка проблеми. Education and psychology in the twenty-first century are witnessing a profound epistemological transition—from mechanistic systems of control, prediction, and standardization toward dynamic systems characterized by emergence, adaptation, and collective intelligence. The convergence of multiple global crises—the COVID-19 pandemic, accelerating climate change, rapid AI development, and the erosion of traditional institutional authority—has revealed the fundamental limits of centralized, hierarchical educational institutions. What increasingly sustains human collectives is not top-down management but bottom-up self-organization, distributed attention networks, and collective meaning-making processes that thrive under conditions of uncertainty (Hasse, 2019; Atchley et al., 2024) [1], [2]. At the heart of this transition lies a fundamental shift in how we understand coordination and learning. The concept of stigmergy—coordination through traces left in the environment—*offers a powerful lens for understanding how complex collective behaviors emerge without central control* (Grassé, 1959; Heylighen, 2016) [3], [4]. In biological systems, termites build intricate structures through simple pheromone deposits; in human systems, learners construct knowledge through the accumulation of cognitive and affective traces in shared environments. Every note on a whiteboard, every comment in a discussion thread, every pause in dialogue becomes a stigmergic trace that shapes subsequent responses and guides collective exploration.

The logic of swarm intelligence, originally developed through observations of social insects and later applied to computational systems, converges with stigmergic principles to offer a compelling model for rethinking facilitation and

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learning as fundamentally ecological processes. Recent scholarship in posthumanist education has begun to challenge the anthropocentric assumptions underlying traditional pedagogical approaches, arguing instead for a decentering of human subjectivity in favor of understanding intelligence as distributed across human-nonhuman assemblages (Braidotti, 2013, 2019; Wang & Wang, 2025) [5], [6], [7]. This shift aligns with the core principles of Eco-Centered Psychological Facilitation (ECPF), which views psychological and educational transformation as emerging from the dynamic interplay between agents, environments, and temporal rhythms rather than from individual cognitive processes alone (Lushyn, 2002, 2013; Lushyn & Sukhenko, 2024, 2025) [8], [9], [10], [11].

The current paper advances this conversation by proposing that swarm intelligence, stigmergic coordination, and ECPF converge on a shared understanding of facilitation as ecological tuning—a practice that creates conditions for collective intelligence to emerge through minimal intervention, rhythmic governance, and the cultivation of environmental traces. This approach introduces the verb "to stigmergize" as a way of naming the active process through which learners co-create meaning by leaving and responding to traces in their shared cognitive ecology. This framework has profound implications for how we conceptualize learning environments, design AI-mediated educational technologies, and understand the role of teachers and facilitators in posthuman educational ecologies.

Analysis of (major) recent research and publications / Аналіз (основних) останніх досліджень і публікацій. The concept of swarm intelligence as a scientific paradigm originated in detailed studies of social insects, particularly ants, bees, and termites (Bonabeau, Dorigo, & Theraulaz, 1999; Gordon, 2010) [12], [13]. These organisms demonstrate remarkable collective problem-solving capabilities despite individual cognitive limitations, achieving complex outcomes through simple, local interactions mediated by environmental traces. The discovery of stigmergy by Grassé (1959) revealed the mechanism underlying this coordination: agents modify their environment, and these modifications guide the behavior of other agents, creating a self-reinforcing cycle of collective action without central control [3].

Recent advances have extended these principles beyond biological systems to encompass artificial swarms, hybrid human-AI systems, and even urban dynamics (Aceves-Fernández, 2023; Batty, 2012) [14], [15]. Studies in cognitive systems and social computation provide further evidence that swarm-like coordination principles underlie emergent collaboration in mixed human–AI teams (Westby & Riedl, 2023; Woolley, Chabris, Pentland, Hashmi, & Malone, 2010) [16], [17]. Heylighen has systematized stigmergy as a universal

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coordination mechanism, distinguishing between marker-based stigmergy (where agents leave explicit signals) and sematectonic stigmergy (where the work itself becomes the coordinating trace) [4]. This distinction proves crucial for understanding educational environments, where both explicit artifacts (assignments, notes) and implicit patterns (discussion rhythms, collective attention) serve as stigmergic traces. Pedagogical research on AI-mediated learning environments increasingly confirms that coordination, reflection, and collective creativity operate through similar stigmergic dynamics (Bearman & Ajjawi, 2023; Boussouf, Amrani, Zerhouni Khal, & Daidai, 2024) [18], [19].

Eco-Centered Psychological Facilitation (ECPF) represents a radical departure from traditional psychological interventions that privilege individual agency and linear causality. Developed through decades of practice and theoretical refinement, ECPF positions the facilitator not as an expert who diagnoses and treats, but as a participant in an ecological field who tunes conditions for emergent transformation (Lushyn, 2013; Lushyn & Sukhenko, 2023) [9], [10]. This approach resonates deeply with stigmergic principles: the facilitator becomes a keeper of traces, one who perceives where meaning accumulates or dissipates and adjusts the environment to support collective self-organization.

The posthumanist turn in psychology and education challenges fundamental assumptions about human exceptionalism, individual autonomy, and the boundaries between self and environment (Braidotti, 2019; Barad, 2003; Burriss, 2024; Al-Omari & Al-Omari, 2025; Yan, 2024) [6], [20], [21], [22], [23]. This intellectual movement is paralleled by posthuman pedagogical frameworks that emphasize relational ethics, distributed cognition, and learning as an entanglement of human and nonhuman agencies (Taylor & Bayley, 2019; Nath & Sahu, 2020) [24], [25].

The theoretical foundations of distributed cognition provide a crucial bridge between swarm intelligence, stigmergy, and ECPF. Hutchins' (1995) groundbreaking work demonstrated that cognitive processes extend beyond individual minds to encompass tools, representations, and social interactions [26]. Later developments in this area have integrated distributed cognition with theories of collective and hybrid intelligence, illustrating how human groups and AI systems co-create emergent cognitive ecologies (Westby & Riedl, 2023; Wang et al., 2024) [16], [27]. Sawyer's (2003) research on group creativity further illuminates how collaborative emergence occurs through the interplay of individual contributions and collective dynamics, revealing patterns strikingly similar to stigmergic coordination in biological swarms [28].

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AIM AND TASKS / МЕТА ТА ЗАВДАННЯ

Aim of the article: To develop a theoretical framework integrating swarm intelligence principles, stigmergic coordination mechanisms, and Eco-Centered Psychological Facilitation (ECPF) for reimagining education and psychological practice in the posthuman era, revealing how collective intelligence emerges through ecological tuning and environmental trace-making rather than hierarchical control.

Research ***objectives***: a) Synthesize swarm intelligence, stigmergy theory, and ECPF to conceptualize facilitation as ecological tuning; b) Analyze rhythmic, stigmergic, and minimal intervention principles as mechanisms of collective intelligence emergence; c) Introduce and develop the concept of "stigmergizing" as an active verb for collective meaning-making; d) Investigate AI as swarm partner and trace-maker in hybrid human-AI learning environments; e) Develop design principles for posthuman educational ecologies based on stigmergic coordination; f) Formulate ethical framework for AI-mediated collective learning based on transparency, diversity, metacommunication, and minimal intervention.

THEORETICAL FRAMEWORK / ТЕОРЕТИЧНІ ОСНОВИ

The research synthesizes: swarm intelligence principles (Bonabeau et al., 1999; Gordon, 2010) [12], [13] conceptualizing collective problem-solving through simple local interactions; stigmergy theory (Grassé, 1959; Heylighen, 2016) [3], [4] explaining coordination through environmental traces; distributed cognition theory (Hutchins, 1995) [26] extending cognitive processes beyond individual minds; posthumanist philosophy (Braidotti, 2013, 2019; Barad, 2003) [5], [6], [16] challenging anthropocentric assumptions; Eco-Centered Psychological Facilitation (ECPF) (Lushyn, 2002, 2013; Lushyn & Sukhenko, 2024, 2025) [8], [9], [10], [11] positioning facilitation as ecological tuning; and group creativity research (Sawyer, 2003) [28] revealing collaborative emergence patterns.

RESEARCH METHODS / МЕТОДИ ДОСЛІДЖЕННЯ

This study employs a multi-methodological approach combining theoretical synthesis, conceptual analysis, and integrative review to explore the convergence of swarm intelligence principles with educational psychology. The research design follows a transdisciplinary framework that bridges complexity science, posthumanist philosophy, and educational practice.

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RESEARCH RESULTS / РЕЗУЛЬТАТИ ДОСЛІДЖЕННЯ

1. From Control to Coordination: The Swarm Paradigm in Educational Psychology

The swarm intelligence paradigm represents a fundamental departure from mechanistic models of education that position teachers as controllers and students as passive recipients. In swarm systems, intelligence emerges from the bottom up through processes of self-organization, adaptation, and collective problem-solving. This shift from control to coordination has profound implications for educational psychology, suggesting that learning environments should be understood as complex adaptive systems where patterns of understanding emerge through distributed interactions rather than centralized instruction.

The mechanism of stigmergy provides the crucial link between abstract swarm principles and concrete educational practices. In a traditional classroom, the teacher's lesson plan serves as a central organizing structure. In a stigmergic learning environment, organization emerges through the traces left by participants: a student's question becomes a cognitive marker that attracts collective attention; a breakthrough insight creates a conceptual attractor around which further exploration crystallizes; even confusion and uncertainty leave affective traces that signal areas requiring collective effort. Consider how online collaborative platforms exemplify stigmergic learning: Wikipedia articles evolve through countless micro-contributions, each edit leaving a trace that guides subsequent modifications; GitHub repositories grow through distributed coding efforts coordinated by commit messages and issue tracking; discussion forums self-organize around emergent themes as participants respond to and build upon each other's posts. These digital environments make visible what has always occurred in human learning: the gradual accumulation and refinement of collective understanding through trace-based coordination. The implications for educational design are transformative. Rather than structuring learning through predetermined sequences and outcomes, stigmergic education creates rich environments where traces can accumulate and interact. This might involve physical spaces with writable walls where ideas can be deposited and connected, digital platforms that preserve and visualize the evolution of collective thinking, or structured dialogues where each contribution explicitly builds on previous traces. The curriculum becomes less a fixed path than an emergent trajectory shaped by the collective's exploration.

2. Stigmergic Facilitation: The Art of Trace Cultivation

Eco-Centered Psychological Facilitation, when viewed through the lens of stigmergy, reveals itself as the art of trace cultivation. The facilitator's role

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transforms from information transmitter to environmental architect—one who shapes the conditions under which productive traces can emerge, persist, and interact. This requires a fundamental shift in pedagogical consciousness: from asking "What should students learn?" to "What traces will enable collective discovery?"

The facilitator as trace-keeper performs several crucial functions:

- Perceiving traces—identifying where meaning accumulates or dissipates in the learning environment, recognizing both explicit markers (written work, verbal contributions) and implicit signals (energy shifts, attention patterns, emotional currents).
- Preserving productive traces—ensuring that valuable insights, questions, and connections remain accessible to the collective, creating archives and repositories of collective thinking.
- Pruning obsolete traces—recognizing when certain patterns have exhausted their generative potential and need to be cleared to make space for new emergence.
- Amplifying weak signals—detecting nascent patterns that might otherwise be overlooked and bringing them to collective attention.
- Connecting distant traces—identifying non-obvious relationships between different threads of exploration and creating bridges between them.

This practice requires what might be called "ecological sensitivity"—the ability to sense the system's dynamics without imposing predetermined structures. Like a gardener who knows when to water, when to prune, and when to simply observe, the stigmergic facilitator works with the system's inherent tendencies rather than against them. This involves recognizing that silence can be as important as speech (a pause creates space for new traces to emerge), that confusion often precedes breakthrough (disorientation signals the dissolution of old patterns), and that resistance indicates the presence of important boundaries that need to be honored rather than overcome.

3. To Stigmergize: A New Verb for Collective Becoming

The introduction of "stigmergize" as an active verb captures the dynamic process through which learners participate in collective intelligence. To stigmergize means to actively contribute to the shared cognitive ecology through the creation and response to environmental traces. It names a mode of engagement that is neither purely individual nor purely collective, but rather exists in the space between—where personal understanding and collective meaning co-evolve through mutual influence. When students stigmergize in discussion-based learning, they leave cognitive residues that others can build upon: a provocative question that reframes the conversation, an example that

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illuminates an abstract concept, an emotional response that signals the importance of particular themes. In project-based learning, teams stigmergize through iterative cycles of creation and modification, each member's contribution becoming a trace that guides subsequent work. Even in solitary study, learners stigmergize with their past and future selves through notes, annotations, and reflections that create a personal ecology of understanding. The concept of stigmergizing challenges traditional notions of individual achievement and assessment. If learning emerges through collective trace-making, then evaluation must consider not just what individuals know but how they contribute to the collective's capacity for understanding. This might involve assessing the quality of questions posed, the connections made between different ideas, the ability to build productively on others' contributions, or the capacity to synthesize diverse traces into coherent patterns. The focus shifts from measuring static knowledge to evaluating dynamic participation in collective meaning-making.

In AI-enhanced learning environments, the concept of stigmergizing takes on new dimensions. AI systems can serve as sophisticated trace-makers, synthesizing patterns across vast scales of interaction, identifying emergent themes, and generating new traces that prompt further exploration. When an AI summarizes a discussion, it creates a meta-trace that reflects the collective's thinking back to itself, often revealing patterns that were implicit in the individual contributions. This creates opportunities for what might be called "algorithmic stigmergy"—where human and artificial agents co-create understanding through iterative trace-making and response.

4. Metacommunication and Collective Reflexivity in Learning Swarms

While stigmergy describes the implicit mechanics of coordination, metacommunication provides the explicit reflective dimension that transforms mechanical swarms into conscious learning collectives. Metacommunication—communication about communication—allows a learning group to become aware of its own dynamics, to recognize the patterns it is creating, and to intentionally modulate its collective behavior (Lushyn & Sukhenko, 2025) [11]. In educational contexts, metacommunicative moments might sound like: "I notice we keep returning to questions of power and agency," or "The energy in our discussion seems to shift when we move from theory to practice," or "Looking at our collective work, there's a pattern of starting with critique before moving to construction." These observations create second-order traces that map the topology of the group's exploration, making visible the usually invisible dynamics of collective thinking. The integration of metacommunication with stigmergic processes creates what might be called "conscious swarms"—collectives that can observe and intentionally shape their own dynamics. This represents a crucial

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advance beyond biological swarms, which operate through unconscious mechanisms. Human learning collectives, enhanced by metacommunicative awareness, can recognize when they are stuck in repetitive patterns, when new directions are emerging, when diversity is being suppressed, or when breakthrough is imminent. The facilitator plays a crucial role in cultivating metacommunicative capacity, modeling the practice of stepping back to observe collective patterns, creating regular opportunities for the group to reflect on its process, and developing shared vocabulary for describing collective states and transitions. This might involve techniques such as: process checks where the group pauses to examine how it is working together; mapping exercises that visualize the evolution of collective understanding; retrospective analyses that identify successful and unsuccessful patterns of collaboration; experiments with different modes of interaction to expand the collective's repertoire.

5. Practical Applications: Stigmergic Design Principles for Learning Environments

The synthesis of swarm intelligence, stigmergy, and ECPF yields concrete design principles for creating learning environments that support collective intelligence. These principles apply across diverse contexts—from traditional classrooms to online courses, from professional development workshops to community learning initiatives.

Principle 1: Rich Trace Environments

Create multiple channels for trace-making and preservation. This might include physical artifacts (whiteboards, sticky notes, visual displays), digital repositories (shared documents, wikis, forums), and processual traces (recorded discussions, version histories, learning portfolios). The environment should make the history of collective thinking visible and accessible, allowing participants to see not just current ideas but their evolution over time.

Principle 2: Rhythmic Variation

Alternate between phases of divergent exploration (generating new traces) and convergent synthesis (consolidating and connecting traces). Build in regular rhythms of action and reflection, individual work and collective engagement, structured activities and open exploration. Recognize that learning swarms need both stimulation and rest, novelty and repetition, chaos and order.

Principle 3: Minimal Sufficient Structure

Provide just enough structure to enable productive stigmergy without constraining emergence. This might involve simple rules of engagement ("build on others' ideas," "make thinking visible," "embrace productive confusion"), clear boundaries (time, space, scope), and scaffolding that can be gradually removed as the collective develops its own organizing patterns.

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Principle 4: Diversity Amplification

Actively cultivate and protect cognitive diversity, recognizing that swarm intelligence depends on varied perspectives and approaches. Create conditions where different types of contributions are valued (questions as much as answers, emotions as much as logic, images as much as words). Design activities that draw on multiple intelligences and ways of knowing.

Principle 5: Metacognitive Scaffolding

Build in regular opportunities for collective reflection and process awareness. Teach the vocabulary of collective dynamics, model metacommunicative practices, and create rituals for stepping back to observe patterns. Develop tools for visualizing collective thinking (concept maps, discussion networks, progress trackers) that make abstract processes concrete.

6. Case Studies: Stigmergic Learning in Practice

To illustrate these principles in action, consider three case studies of stigmergic learning environments:

Case 1: The Philosophy for Children Circle

In a Philosophy for Children session following Matthew Lipman's approach, young learners sit in a circle discussing a philosophical story [29]. Each child's question or observation becomes a trace that others can follow or diverge from. The facilitator tracks these traces on a visible board, creating a map of the collective's exploration. Children learn to "stigmergize" by building on each other's ideas, recognizing patterns in their collective thinking, and developing metacommunicative skills through regular process reflections. The circle itself becomes a living algorithm for collective sense-making, with understanding emerging not from any individual insight but from the accumulation and interaction of diverse perspectives.

Case 2: The AI-Enhanced Graduate Seminar

A graduate seminar in educational psychology uses an AI system to track and synthesize discussion patterns across sessions. Students contribute to a shared digital workspace where their reflections, questions, and insights accumulate. The AI periodically generates syntheses that identify emergent themes, unresolved tensions, and potential connections. These AI-generated traces become objects for further collective reflection, with students learning to work with the AI as a stigmergic partner rather than an authority. The seminar develops its own unique "cognitive signature"—patterns of inquiry and understanding that emerge from the specific configuration of human and artificial participants.

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Case 3: The Trauma-Informed Learning Community

A learning community for educators working with trauma-affected students employs ECPF principles to create a supportive environment for professional development. Participants share experiences and insights through multiple modalities—verbal sharing, artistic expression, somatic exercises. These diverse traces create a rich ecology of understanding that honors both cognitive and embodied knowledge. The facilitator maintains a "living document" that captures the community's evolving wisdom, with members contributing asynchronously between meetings. The stigmergic accumulation of practical wisdom creates a resource that transcends any individual's expertise, demonstrating how collective intelligence can emerge from shared vulnerability and mutual support.

7. Ethical Implications and Critical Considerations

7.1. The Human Dimension of Swarms

While swarm intelligence and stigmergy offer powerful models for understanding collective learning, critical examination reveals important ethical considerations. Human collectives differ fundamentally from insect swarms in their capacity for individual agency, moral reasoning, and conscious choice. The application of swarm principles to education must therefore respect the irreducible dignity and autonomy of each participant while enabling collective emergence. The concept of stigmergizing helps navigate this tension by positioning learners as active agents who consciously contribute to collective patterns while maintaining individual identity and choice. Unlike ants following pheromone trails, humans can recognize, reflect on, and deliberately modify the traces they create and follow. This metacognitive capacity transforms potentially mechanistic processes into opportunities for ethical development and critical consciousness.

7.2. Power, Access, and Stigmergic Equity

The ability to create and respond to traces is not equally distributed. Some participants may dominate trace-making through volume, authority, or cultural capital, while others' contributions may be systematically overlooked or erased. Digital stigmergic environments can amplify these inequalities if not carefully designed, as algorithmic amplification may privilege certain types of traces over others. Addressing these concerns requires intentional design for stigmergic equity: ensuring multiple channels for trace-making that accommodate different communication styles and abilities; actively amplifying traces from marginalized voices; creating protocols that prevent trace monopolization; and developing collective awareness of power dynamics in trace creation and response. The facilitator's role includes monitoring for stigmergic justice, ensuring that the

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collective intelligence genuinely represents the diversity of its participants rather than the amplified voices of a few.

7.3. Data Ethics and Trace Ownership in Digital Learning Ecologies

In digital learning environments, stigmergic traces become data that can be stored, analyzed, and potentially commodified. This raises critical questions about ownership, privacy, and the use of collective intelligence. Who owns the traces created in collaborative learning? How should the collective intelligence that emerges from stigmergic interaction be attributed and protected? What rights do participants have over their contributions to the collective cognitive ecology? ECPF's ethical framework emphasizes that traces generated through collective learning belong to the collective and should primarily benefit participants rather than external stakeholders. This principle challenges dominant models of educational data mining that extract value from student activities for institutional or commercial purposes. It suggests the need for new models of collective ownership and governance of educational data, where participants maintain agency over the traces they create and the patterns that emerge from their interaction (Table).

Table

Comparison of Traditional and Stigmergic Educational Approaches

Dimension	Traditional Approach	Stigmergic Approach
Coordination Mechanism	Centralized control through curriculum and instruction	Distributed coordination through environmental traces
Knowledge Construction	Linear transmission from teacher to student	Emergent co-creation through collective trace-making
Role of Facilitator	Information provider and evaluator	Trace-keeper and ecological tuner
Learning Environment	Structured space with predetermined pathways	Rich trace environment enabling self-organization
Assessment Focus	Individual achievement and knowledge retention	Contribution to collective intelligence
Temporal Organization	Fixed schedules and sequences	Rhythmic variation responsive to emergence

Note: This table synthesizes key distinctions between traditional pedagogical approaches and the stigmergic educational framework proposed in this paper. The stigmergic approach emphasizes emergent, distributed, and ecological processes that enable collective intelligence to flourish in educational settings.

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CONCLUSIONS / ВИСНОВКИ

The convergence of swarm intelligence, stigmergic coordination, and Eco-Centered Psychological Facilitation opens radical new possibilities for reimagining education in the posthuman era. By understanding learning as an ecological process characterized by distributed intelligence, trace-based coordination, and rhythmic self-organization, we can move beyond the limitations of industrial-era educational models toward more adaptive, creative, and collectively intelligent learning systems.

The introduction of stigmergy as a core concept in educational theory provides a concrete mechanism for understanding how collective intelligence emerges in learning environments. Through the active process of stigmergizing—creating and responding to environmental traces—learners participate in a form of collective becoming that transcends individual cognition while respecting individual agency. This framework offers practical tools for designing learning environments that support emergence, diversity, and collective creativity. The facilitator in this new paradigm becomes neither sage nor guide but gardener of traces and keeper of rhythms—one who cultivates conditions for collective intelligence to flourish while trusting in the system's capacity for self-organization. This requires new competencies, including ecological sensitivity, comfort with uncertainty, metacommunicative skill, and the ability to work with rather than against emergent processes. It also requires new ethical frameworks that honor the agency of all participants—human and non-human—in the learning ecology while addressing issues of power, access, and data ownership in stigmergic systems.

The practical applications of this framework extend across educational contexts, from early childhood Philosophy for Children circles to AI-enhanced graduate seminars, from professional learning communities to massive online collaborations. In each setting, the principles of stigmergic learning—rich trace environments, rhythmic variation, minimal sufficient structure, diversity amplification, and metacognitive scaffolding—create conditions for genuine collective intelligence to emerge.

As we face accelerating global changes and the rapid evolution of AI capabilities, the need for educational approaches that cultivate collective intelligence becomes ever more urgent. The ability to stigmergize effectively—to contribute meaningfully to collective sense-making through environmental traces—may become one of the most important competencies of the 21st century. ECPF offers not a fixed method but a set of principles and practices for working with the fundamental forces that enable learning and transformation.

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In this vision, education transforms from a process of individual knowledge acquisition to a collective journey of becoming—one where to teach is to tune, to learn is to resonate, to think is to swarm together, and to understand is to stigmergize meaning from the traces we leave for each other. The classroom becomes a living cognitive ecology, the curriculum an emergent trajectory, and assessment a recognition of contribution to collective intelligence. The implications extend far beyond classroom walls, suggesting new ways of organizing human collectives, designing technologies, and navigating the complex challenges of the Anthropocene. As boundaries between human and artificial intelligence continue to blur, the framework of stigmergic learning provides a way to understand and design human-AI collaboration that enhances rather than replaces human agency. The future of education lies not in choosing between human wisdom and artificial intelligence but in learning to dance together in the space between—creating new forms of collective intelligence through the artful cultivation of traces, the patient tending of rhythms, and the courageous embrace of emergence.

Ultimately, this framework invites us to reconceptualize learning itself—not as the filling of individual minds with predetermined content, but as participation in the ongoing creation of collective meaning. To stigmergize is to contribute to something larger than oneself while maintaining one's unique perspective and agency. It is to trust that intelligence emerges not from control but from connection, not from hierarchy but from ecology, not from instruction but from interaction. In embracing this vision, we open possibilities for educational futures that are more democratic, more creative, and more adequate to the challenges and opportunities of our posthuman future.

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ТАНЕЦЬ З РОЄМ: ЕКОЛОГІЧНА ПСИХОЛОГІЧНА ФАСИЛІТАЦІЯ І МАЙБУТНЄ НАВЧАННЯ

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Анотація. Ця стаття досліджує зближення принципів ройового інтелекту, стигмергійної координації та екологічної психологічної фасилітації (ECPF) як трансформаційної рамки для переосмислення освіти та психології в епоху постгуманізму. Спираючись на сучасні дослідження колективного інтелекту, розподіленого пізнання, стигмергійної координації та навчальних середовищ, опосередкованих ШІ, автори доводять, що психологічну та освітню фасилітацію слід переосмислити як екологічне налаштування – майстерне створення ритмічних, просторових та реляційних умов, які

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уможливлюють емерджентну самоорганізацію через сліди, залишені в середовищі. Концепція стигмергії – координації через сліди у навколишньому середовищі – пропонує конкретний механізм для розуміння того, як колективний інтелект виникає в освітніх просторах. Через інтеграцію інсайтів з науки про складність, урбаністичного морфогенезу, постгуманістичної філософії та етичних рамок ШІ, це дослідження окреслює комплексні принципи дизайну для гібридних людино-ШІ навчальних середовищ, в яких учасники активно «стигмергізують» значення/смисли через ітеративне створення слідів. Запропоновано екологічну етику мінімального втручання в поєднанні з метакомунікативною усвідомленістю як основу для психологічної та освітньої трансформації, позиціонуючи фасилітатора як диригента темпоральних ритмів, хранителя стигмергійних слідів та культиватора колективної рефлексивності. Імплікації виходять за межі традиційних педагогічних границь, пропонуючи нові можливості для розуміння розвитку людини, колективного інтелекту та коеволюції людських та штучних когнітивних систем в освітніх контекстах через призму стигмергійної координації в процесі самоорганізації.

Ключові слова: ройовий інтелект; екологічна психологічна фасилітація (ECPF); стигмергія; стигмергійна координація; ШІ в освіті; розподілене пізнання; постгуманізм; колективний інтелект; гібридні навчальні середовища; спонтанна самоорганізація; екологічне налаштування; освітня трансформація; співпраця людини і ШІ; метакомунікація; сліди в середовищі; колективна рефлексивність.

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