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# СТИГМЕРГІЯ ЯК МІКРОМЕХАНІЗМ КОГНІТИВНИХ ІНТЕРФЕЙСНИХ ЗСУВІВ У ВИЩІЙ ОСВІТІ: ЕКОЦЕНТРОВАНИЙ ПСИХОЛОГІЧНИЙ ФАСИЛІТАТИВНИЙ ПІДХІД

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# STIGMERGY AS A MICROMECHANISM OF COGNITIVE INTERFACE SHIFTS IN HIGHER EDUCATION: AN ECO-CENTERED PSYCHOLOGICAL FACILITATION APPROACH

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***Abstract.*** *The growing discrepancy between linear models of instructional design and the actual dynamics of cognitive processes in learning groups calls for new theoretical tools capable of describing self-organization in the university classroom. This article explores stigmergy—a mechanism of indirect coordination through environmental traces—as a micromechanism of cognitive interface shifts in higher education. The aim is to conceptualize stigmergy as the mechanism underlying learning group transitions between interpretive frames and to reconceptualize the instructor-facilitator as a cartographer of desire paths within Eco-Centered Psychological Facilitation (ECPF). The methodology combines theoretical synthesis and conceptual analysis, integrating the biological theory of stigmergy (Grassé, 1959; Heylighen, 2016a), the theory of cognitive interfaces (Hoffman, 2019), distributed cognition frameworks (Hutchins, 1995), and ECPF (Lushyn & Sukhenko, 2025a, 2025b). Drawing on modified illustrative examples from practical sessions in psychology and philosophy of education courses, the article identifies five types of stigmergic traces—questions, emergent functional expertise, silence as a rhythmic marker, latent traces, and format contagion—and their corresponding cognitive interface shifts. The urbanistic phenomenon of desire paths is proposed as a unifying metaphor that structures a four-phase process model of stigmergic interface shift: rupture, search, formation, and integration. The facilitator's role is reconceptualized through four functions: detecting emerging trails, introducing calibrated dissonance, sustaining forks without premature closure, and protecting the ecosystem of trails. It is shown that core ECPF principles function not merely as ethical guidelines but as descriptions of how stigmergic coordination operates in educational environments. Further research may pursue empirical verification of the model and development of AI-supported tools for stigmergic facilitation.*

***Keywords:*** *stigmergy, Eco-Centered Psychological Facilitation (ECPF), cognitive interface shift, self-organization, distributed cognition, posthumanist pedagogy, swarm intelligence.*

***Formulas:0, fig.: 0, tab.: 1, bibl.: 17***

***Анотація.*** *Зростаюча невідповідність між лінійними моделями організації навчального процесу та реальною динамікою когнітивних процесів у навчальних групах потребує нових теоретичних інструментів для опису самоорганізації в університетській авдиторії. Стаття досліджує стигмергію – механізм непрямої координації через сліди в середовищі – як мікромеханізм когнітивних інтерфейсних зсувів у вищій освіті. Мета – концептуалізувати стигмергію як механізм переходу навчальної групи між інтерпретативними рамками та переосмислити позицію викладача-фасилітатора як картографа стежок бажання (desire paths) у вимірах*

*екоцентрованої психологічної фасилітації (ECPF). Методологія поєднує теоретичний синтез та концептуальний аналіз, інтегруючи біологічну теорію стигмергії (Grassé, 1959; Heylighen, 2016a), теорію когнітивних інтерфейсів (Hoffman, 2019), концепції розподіленого пізнання (Hutchins, 1995) та ECPF (Lushyn & Sukhenko, 2025a, 2025b). На матеріалі модифікованих ілюстративних ситуацій, що відбувалися на семінарах курсів психології та філософії освіти ідентифіковано п'ять типів стигмергічних слідів – запитання, емерджентна функціональна експертиза, мовчання як ритмічний маркер, латентний слід та зараження форматом – та відповідні когнітивні інтерфейсні зсуви. Урбаністичний феномен desire paths запропоновано як узагальнюючу метафору, що структурує модель стигмергічного зсуву з чотирьох фаз: розрив, пошук, формування, інтеграція. Роль фасилітатора переосмислено через чотири функції: виявлення нових стежок, введення каліброваного дисонансу, підтримка розвилок без передчасного закриття та захист екосистеми стежок. Показано, що принципи ECPF є не лише етичними настановами, а й описом механізму стигмергічної координації в освітньому середовищі. Перспективи пов'язані з емпіричною верифікацією моделі та розробкою інструментів AI-підтримки стигмергічної фасилітації.*

***Ключові слова:*** *стигмергія, Екоцентрована психологічна фасилітація (ECPF), когнітивний інтерфейсний зсув, самоорганізація, розподілене пізнання, постгуманістична педагогіка, ройовий інтелект.*

***Формул: 0; рис.: 0, табл.: 0, бібл.: 17***

**Introduction.** One of the persistent paradoxes of university education is that the most productive intellectual movements in a classroom rarely coincide with the pre-planned structure of the instructional process. The syllabus sets one structure, the assessment system another, institutional expectations a third. Yet a genuine cognitive shift often occurs in a zone that is difficult to anticipate: at the moment when a student poses an unexpected question, when the pause following a complex statement proves more productive than the statement itself, when a metaphor uttered in passing begins to organize the entire subsequent discourse.

There exists a precise scientific term for this phenomenon—*stigmergy*. It was introduced by the French entomologist Pierre-Paul Grassé in 1959 while studying the building behavior of termites (Grassé, 1959). Stigmergy denotes a mechanism of indirect coordination in which the trace left by an action in a medium stimulates subsequent actions (Heylighen, 2016a). Termites do not coordinate their behavior directly: one deposits a lump of clay marked with pheromone; another, sensing it, places its own nearby. No one directs the process. No one possesses an overall plan. Yet from these local, indirect modifications of the environment, a termite mound emerges—a structure whose complexity long resisted explanation without the assumption of a central coordinator (Theraulaz & Bonabeau, 1999; Bonabeau et al., 1999).

In educational systems, traces are not material but symbolic in nature. They manifest as questions, silences, speech patterns, recurring metaphors, shared documents, or digital artifacts. When interpreted through the lens of Eco-Centered Psychological Facilitation (ECPF), stigmergy acquires the status of a micromechanism through which learning groups accomplish transitions between cognitive interfaces—from one interpretive frame to another (Lushyn & Sukhenko, 2025a, 2025b). This article integrates stigmergic theory, the theory of cognitive interfaces (Hoffman, 2019), concepts of swarm intelligence and distributed cognition (Hutchins, 1995; Holland, 1995) with the practice of eco-centered psychological facilitation, demonstrating their applicability to the analysis of self-organizing processes in the university classroom.

**Review of Recent Research and Publications.** *Stigmergy: From Biology to Social Systems.* The concept of stigmergy was introduced by Grassé (1959) to explain the coordination of building activity in termites and subsequently gained wide currency in complexity theory. Heylighen (2016a) formalized the definition of stigmergy as “a mechanism of indirect coordination in which the trace left by an action in a medium stimulates subsequent actions” (p. 4), identifying its key components: agent, action, medium, trace, and coordination. In a subsequent work, Heylighen (2016b) developed a typology of stigmergic mechanisms, distinguishing between

quantitative and qualitative stigmergy, as well as sematectonic and marker-based traces. Theraulaz and Bonabeau (1999) presented a historical retrospective of the concept, demonstrating its applicability to explaining diverse forms of collective behavior in social insects.

Bonabeau, Dorigo, and Theraulaz (Bonabeau et al., 1999) systematized the principles of swarm intelligence, showing how complex global structures emerge from simple local behavioral rules. Holland (1995) described analogous processes in the theory of complex adaptive systems, introducing the concept of "hidden order"—latent organizing principles that manifest through the interaction of system elements. In the context of distributed cognition, Hutchins (1995) demonstrated that cognitive processes are not confined to the individual brain but are distributed across people, artifacts, and the environment, thereby creating a conceptual foundation for understanding stigmergic processes in education. Correia, Sebastião, and Santana (2017) further explored this intersection, examining the role of stigmergy as a mechanism underlying cognitive processes themselves.

*Cognitive Interfaces and Interface Shifts.* Hoffman's theory of cognitive interfaces (Hoffman, 2019) proposes a radical revision of the relationship between perception and reality. According to his Interface Theory of Perception (ITP), a cognitive interface constitutes an interpretive system through which an individual perceives, evaluates, and acts upon reality. Perception functions not as a "window onto reality" but as a user interface, evolutionarily optimized for fitness rather than truth. In the educational context, an interface shift occurs when the prior interpretive frame becomes insufficient—when the habitual mode of understanding can no longer accommodate new experience.

This theory finds complement in the work of Prigogine and Stengers (1984) on dissipative structures and bifurcation points, as well as in self-organization theory, according to which far-from-equilibrium systems are capable of spontaneously transitioning to qualitatively new states through the amplification of fluctuations. Within the ECPF framework, crises and moments of uncertainty are regarded not as failures but as bifurcation points—moments in which a system may transition to a qualitatively new state (Lushyn & Sukhenko, 2025b).

*Eco-Centered Psychological Facilitation (ECPF).* ECPF is a non-clinical modality of psychological and pedagogical support that has been developed by the author since 2002 (Lushyn, 2002). It rests on the understanding that development occurs not through the correction of deficits but through the ecological support of adaptive self-organization. The monograph-textbook *ECPF: Eco-Centered Psychological Facilitation in Psychological and Educational Practice with Artificial Intelligence* (Lushyn & Sukhenko, 2025b) presents a comprehensive model of eco-facilitation integrating eleven principles: ecological systemicity, contextuality, collaboration, dialectical paradoxicality, tolerance for uncertainty, non-deficit development, person-centered development, processuality, practical brevity, nonlinearity, and innovative conservation.

Within the ECPF framework, swarm intelligence and stigmergic coordination are treated as models for understanding collective cognitive processes. In the article "Dancing with swarms: Eco-Centered Psychological Facilitation and the future of learning" (Lushyn & Sukhenko, 2025a), the metaphor of "dancing with the swarm" is developed as a way of describing the facilitative stance—immersion in the collective process without claiming to control it. Research on the transformative potential of the educational environment and on the role of AI as a supportive instrument in the development of psychologists extends the theoretical framework, showing how the principles of eco-facilitation are realized in the context of the digital transformation of education.

*Posthumanist Pedagogy and Distributed Intelligence.* Posthumanist theory (Braidotti, 2013), when applied to pedagogy, radically reconceives the relationship between human and nonhuman agents in the

educational process. Intelligence is understood as distributed across human and technological agents, thereby creating conceptual space for rethinking the role of AI and digital artifacts as participants in a cognitive ecology. Vygotsky (1978) understood development as a socially mediated process, yet his concept of the zone of proximal development—and the subsequent notion of scaffolding developed by Wood, Bruner, and Ross (1976)—presupposed a hierarchical structure of "more knowledgeable–less knowledgeable." The ecological perspective of ECPF extends this model, moving from scaffolding to ecological orchestration—the creation of conditions under which the system itself discovers and realizes its possibilities (Lushyn & Sukhenko, 2025b).

**Research Aim.** The aim of this study is to conceptualize stigmergy as a micromechanism of cognitive interface shifts in higher education and to reconceptualize the position of the instructor-facilitator as a cartographer of desire paths within the framework of Eco-Centered Psychological Facilitation (ECPF).

*Research Tasks:* a) to identify types of stigmergic traces in the university classroom and their corresponding cognitive interface shifts; b) to develop a process model of stigmergic cognitive interface shift structured through the desire paths metaphor; c) to delineate the facilitator's role as cartographer of desire paths through the four functions of ECPF; d) to examine the implications of stigmergic coordination for the theory and practice of higher education, including the role of AI as a digital cartographer.

**Methodology.** All examples presented in this article are illustrative situations created by the author on the basis of modified and generalized experience from practical sessions in a psychology course and eco-centered psychological facilitation (ECPF). Participants' names have been changed and situational details reworked to ensure confidentiality and enhance analytical clarity. The examples do not constitute verbatim observational protocols; they are constructed to illustrate stigmergic mechanisms and cognitive interface shifts that are theoretically grounded in the preceding sections. This approach is consistent with the practice of using modified vignettes in qualitative research in educational psychology.

**Research Results.** ***1. Stigmergy in the Informal Self-Organization of Students.*** Five types of situations are examined below, each demonstrating a particular type of stigmergic trace and its associated cognitive interface shift.

*The Question as a Stigmergic Trace: illustrative situation 1.* During a session on philosophy of education, in a discussion about childhood in the age of AI, a student poses an unfinished question: "What if a child who grows up with an AI assistant never actually develops what we call an 'inner voice'?" The question is neither rhetorical nor provocative: it is unformed, like a sketch. It is precisely this incompleteness that triggers a chain reaction: another student reformulates—"wait, do you mean inner speech or self-reflection in general?"; a third introduces a new context—"I think this connects to what Vygotsky said about internalization"; a fourth objects—"but Vygotsky was talking about social speech, and AI isn't the same as another person."

The original question ceases to be anyone's property. It becomes an environmental trace around which the group reorganizes its collective attention. The transition occurs stigmergically: the trace (the unfinished question) modifies the environment (shifts the focus of group discussion), and each subsequent participant responds not to the original question but to the modified environment. In Heylighen's (2016a) terminology, this is an instance of qualitative stigmergy: the trace alters not the intensity of the response but its directionality. A *cognitive interface shift* occurs: the group transitions from the interface of "knowledge reception" (the instructor speaks—students listen) to the interface of "problem co-construction" (no one knows the answer—everyone extends the question).

*Emergent Functional Expertise: illustrative situation 2.* In a seminar group, a student referred to here as Maria begins

spontaneously performing a particular function: each time the discussion fragments into parallel threads, she says: “wait, let me try to connect these,” and offers a brief synthesizing construction. No one appointed Maria as moderator. Her role emerged stigmergically: the first spontaneous synthesis proved useful; the group responded—nods, continuation of the discussion along the proposed direction. This recognition became an environmental trace that reinforced the behavior. By the second and third occurrence, the pattern had consolidated.

From the perspective of swarm intelligence theory (Bonabeau et al., 1999), a useful cognitive intervention generates a *positive feedback loop*: the environment (the group’s response) amplifies the trace (the synthesizing utterance), which in turn amplifies the role (Maria as informal synthesizer). The cognitive interface shift consists in a transition from hierarchical authority (the instructor is the sole synthesizer) to functional influence based on contribution (whoever is able to synthesize at a given moment does so). This type of distributed cognition has been described by Hutchins (1995) in relation to navigation teams, yet it is equally realized in the learning group as a system of distributed cognitive processing.

*Silence as a Rhythmic Marker: illustrative situation 3.* A student referred to here as Andy remains silent for thirty minutes during a discussion on the nature of justice in education. Then, when a natural pause arises, he utters a single phrase: “It seems to me that we are all talking about justice as if it were a resource to be distributed. What if it is a process that needs to be set in motion?” The group’s reaction is immediate: several people turn toward him simultaneously; a silence of a different quality emerges—not a pause of expectation but a pause of processing.

Andy’s silence performed the stigmergic function of *rhythmic marking*. His prolonged non-participation created a “pressure of anticipation” in the environment—the group sensed the presence of the unspoken. When the utterance occurred, its weight was determined not only by its content but by the accumulated rhythmic contrast. Within the ECPF framework, rhythmic sensitivity is a key characteristic of ecological orchestration: the weight of an utterance is determined not by frequency but by the precision of the moment (Lushyn & Sukhenko, 2025a). Cognitive interface shift: from the dominance of speed to rhythmically sensitive coordination.

*The Latent Trace and Nonlinear Assembly of Meaning: illustrative situation 4.* At the beginning of the semester, a student remarks in passing: “Maybe learning isn’t what the instructor does to the student, but what happens between them when no one planned it.” The phrase was met with nods, but the discussion moved on. Six weeks later, during a discussion of Vygotsky’s zone of proximal development, another student suddenly recalls: “remember, someone at the beginning of the course said that learning is what happens when nobody planned it? I think that *is* the zone of proximal development.”

No formal system of records preserved this phrase. It was retained in the group’s collective memory as a *latent stigmergic trace*. Its return after six weeks demonstrates that the environment of group discussion possesses its own form of distributed retention: ideas do not disappear but pass into a latent state and are reactivated when the context creates a “niche of relevance.” In Heylighen’s (2016b) terminology, this is an instance of long-term stigmergy with variable trace persistence. Cognitive interface shift: from linear dialogue (each utterance is a response to the preceding one) to nonlinear assembly of meaning (ideas from different temporal layers converge).

*Stigmergic Contagion of Format: illustrative situation 5.* A student begins responding to a question about parenting styles narratively: “When I was seven years old, my father…” The instructor does not interrupt. The next student also begins with a personal story. Within fifteen minutes, the format of the discussion has shifted: instead of abstract classifications, the group has moved to exchanging biographical episodes from which theoretical categories are derived inductively.

The stigmergic mechanism here is *contagion by the form of utterance*. The first narrative altered the environment: it demonstrated that this format was permissible and valued. Each subsequent narrative amplified this environmental trace, making the narrative format an increasingly "natural" choice. This corresponds to the mechanism of autocatalytic reinforcement described by Bonabeau and colleagues (Bonabeau et al., 1999): positive feedback nonlinearly increases the probability of pattern repetition. Cognitive interface shift: from argumentative cognition (thinking through logical operations) to experiential cognition (thinking through lived experience and retelling).

*Desire Paths: A Metaphor for Stigmergic Self-Organization in the Learning Group.* The five situations considered above share a common structure that calls for a unifying image. In urban studies, there exists the phenomenon of *desire paths*—spontaneous trails that pedestrians wear into the ground by systematically deviating from architect-designed walkways (Helbing et al., 1997). Each step is a trace; each trace attracts the next; the path deepens without anyone having decided it should exist. Notably, Heylighen (2016a) uses precisely this example to illustrate stigmergy among humans: trails worn by pedestrians represent a canonical case of trace-based coordination, in which the action of one agent modifies the environment such that subsequent agents reproduce and amplify the pattern without any direct interaction.

The syllabus functions precisely as a designed walkway: it lays a route from topic to topic. However, as the five situations demonstrate, the actual cognitive movement of the learning group deviates from this route each time, wearing its own desire paths into the conceptual landscape.

The student's unfinished question about AI and inner speech (4.1) was the first step away from the paved path—uncertain, without a definite direction, but sufficient to draw others along. Maria's spontaneous synthesis (4.2) showed how one participant becomes the guide of a trail she never planned to blaze. Andy's thirty minutes of silence (4.3) functioned as a halt at a fork—a stillness that compelled the group to survey the terrain before a single phrase redirected the route. The phrase recalled after six weeks (4.4) is an overgrown trail rediscovered when a shift in context made it passable again. And the spread of the narrative format (4.5) is the moment when everyone began moving differently: not by agreement, but under the gravitational pull of a trace that altered the very mode of movement. In each case, the cognitive interface shift occurred at the point where the *desire path became the new route*—where the group's self-organized trajectory displaced the planned structure and a qualitatively different interpretive frame took hold.

This metaphor simultaneously delineates the facilitator's position, which the following section examines in detail: not the architect who designed the walkways, nor the traffic controller, but the *cartographer of emerging trails*—one who notices where new paths are forming, tests their viability, maintains signposts at critical forks, and ensures that one dominant trail does not obliterate all the others.

### *2. Eco-Centered Psychological Facilitation (ECPF) as the Ethical Modulation of Stigmergic Processes*

The five situations described and the unifying metaphor of desire paths reveal a common pattern: coordination occurred without direct control. This does not mean, however, that the instructor is unnecessary. The role shifts qualitatively: from architect of walkways to cartographer of trails, from managing discourse to the ecological orchestration of emergent processes. Within the ECPF framework (Lushyn & Sukhenko, 2025b), the facilitator performs four key functions.

*Detecting emerging trails.* The facilitator notices that a particular question, metaphor, or format keeps recurring—much as a cartographer registers the first impressions in the grass, not yet a trail but already indicating the direction of collective movement. If three students in different contexts use the word "system," this constitutes a stigmergic trace indicating that the group is groping toward a

systemic descriptive language. The facilitator makes this explicit: "notice that the word 'system' has appeared three times now—why that word?" In terms of swarm intelligence, this function is analogous to the role of the scout bee, translating implicit information into explicit form (Bonabeau et al., 1999).

*Introducing calibrated dissonance.* When a discussion has stabilized within one interpretive frame—when the desire path has been trodden so firmly that the group no longer notices alternative routes—the facilitator introduces a slight perturbation. Not to destroy the trail, but to test whether it has transformed from a living route into a rut. This corresponds to the principle of "minimal intervention" in ECPF (Lushyn & Sukhenko, 2025a) and is analogous to the concept of "noise" in self-organization theory (Prigogine & Stengers, 1984), necessary to prevent premature stabilization of the system.

*Sustaining forks without premature closure.* One of the facilitator's key functions is resisting the pressure to "choose a route quickly." When the group encounters a contradiction—a point where the trail diverges—the facilitator holds both branches open simultaneously. Tolerance for uncertainty is one of the central principles of ECPF (Lushyn & Sukhenko, 2025b) and a key condition for productive cognitive interface shifts: premature paving of one branch destroys the possibility of discovering a more complex route.

*Protecting the ecosystem of trails.* The facilitator ensures that one dominant desire path does not trample all the others. If one participant systematically "drowns out" others' traces—converting their route into the only one—the facilitator intervenes to restore ecological diversity: "wait, I think that idea hasn't fully unfolded yet. Give it space." This function ensures what in the context of ECPF is called the "ecosystem of differences"—a condition in which the multiplicity of trails is sustained as a resource rather than reduced to a single thoroughfare (Lushyn & Sukhenko, 2025a).

### *3. Stigmergy as a Micromechanism of Cognitive Interface Shift: A Process Model*

The integration of stigmergic theory with the concept of cognitive interfaces makes it possible to describe the process of interface shift through four phases. In the logic of the desire paths metaphor, these phases describe the dynamic from the moment a first pedestrian deviates from the paved walkway to the moment a new trail itself becomes the route.

*Rupture.* Someone takes the first step away from the established route. An unresolved question or tension destabilizes existing meaning structures. In the terminology of self-organization theory (Prigogine & Stengers, 1984), this is a fluctuation whose amplitude exceeds the stability threshold of the current attractor. The habitual cognitive interface—for example, "the world is knowable through the correct method"—proves untenable in the face of new experience. The paved walkway of the syllabus leads somewhere the group does not need to go.

*Search.* Multiple traces fan out: participants try different directions, leaving tentative trails in the conceptual landscape. Each utterance is a stigmergic trace modifying the search space. This stage is analogous to the exploration phase in swarm systems, when agents explore the solution space through distributed search (Holland, 1995). Not all trails will prove viable—some will peter out after the first or second step.

*Formation.* One of the trails begins to attract: a second, third, fifth participant walks along it. Gradually, a new organizing principle stabilizes—one that arises not from individual decision but from the aggregate of stigmergic traces. This is a manifestation of emergence—a property irreducible to the sum of individual agents' contributions (Bonabeau et al., 1999). Trampling studies have shown that as few as fifteen passes over a site can suffice to create a distinct trail that then attracts further use; Helbing and colleagues (1997) developed computational models demonstrating how such feedback dynamics produce self-organized trail systems at scale. In classroom discussion, the analogue is the moment when the group begins using a new term or framework as "its own."

*Integration.* The desire path becomes the new route. Traces consolidate into a shared language, recurring formulations, or digital artifacts. The trace ceases to be "someone's utterance" and becomes an element of the collective cognitive landscape—a trail along which the group moves no longer because anyone so decided but because it has been worn in. The facilitator's role at this stage is to sustain conditions for emergence without imposing premature "paving" (Lushyn & Sukhenko, 2025b): a trail poured with concrete too early loses its capacity to branch.

### *4. Digital Expansion: AI and Distributed Traces*

Digital platforms radically alter the topography of desire paths. In physical space, a trail exists only as long as it is walked: an abandoned trail becomes overgrown. Digital platforms create *persistent traces*—traces that do not become overgrown, are preserved across time, and remain available for re-engagement. Chat discussions, shared documents, collaborative whiteboards, and AI-generated syntheses extend the stigmergic field beyond the immediate classroom interaction. Whereas in the classroom a phrase uttered six weeks earlier (situation 4.4) may be forgotten and serendipitously rediscovered, in the digital environment it is indexed, retrieved, and returned to context—the overgrown trail is cleared algorithmically.

Within the ECPF framework, an AI system can function as a *digital cartographer of desire paths*: detecting emerging trails in a discussion, highlighting abandoned yet potentially generative routes, tracking rhythmic changes in group dynamics, and summarizing emergent themes without authoritative closure. The key condition: AI must function as a cartographer, not an architect (Lushyn & Sukhenko, 2025b). It records where the group is wearing trails, but does not lay paved walkways. It supports the ecological rhythm rather than replacing it. In the posthumanist perspective (Braidotti, 2013), such an AI is a co-agent in a distributed cognitive process—not a tool and not a threat, but another pedestrian in the cognitive landscape whose traces also become part of the shared topography.

### *5. Implications for Theory and Practice in Higher Education*

The analysis presented here allows four implications to be formulated for reconceiving the educational process in higher education. Each may be read through the metaphor of desire paths.

*Learning is emergent, not prescribed.* The syllabus is the design of a walkway; actual learning is the trail worn on top of the design. The content of learning arises from stigmergic interactions within the syllabus framework and often extends beyond it. The educational outcome cannot be fully predetermined by the curriculum, since it emerges as an emergent property of the collective cognitive system (Holland, 1995). The attempt to pave every possible route in advance is precisely the error committed by an overly deterministic instructional design.

*Learning is rhythmic, not linear.* The trail does not lead from point A to point B in a straight line: it meanders, slows at forks, accelerates on descents, returns to places already traversed. Learning does not progress uniformly from topic to topic; it pulsates, and these rhythmic characteristics are not disturbances but structural properties of the ecology of learning (Lushyn & Sukhenko, 2025a). Andry's silence (4.3) is not an absence of movement; it is a halt without which the next step would have been impossible.

*Learning is distributed, not centralized.* A desire path belongs to no one: it was worn by everyone who walked along it. Knowledge does not "reside" in the instructor's head to be "transmitted" to students. It arises in the space between participants, in their traces, responses, and reconfigurations (Hutchins, 1995). The instructor is one of the pedestrians whose traces matter, but not the only one whose traces shape the landscape.

*Learning is interfacial, not content-based.* The principal result of a desire path is not the trail itself but the change in the mode of navigation. The key outcome of education is not the acquisition of content but the capacity to switch between cognitive interfaces: to see

the same problem from different interpretive frames (Hoffman, 2019). Stigmergic facilitation supports precisely this capacity—not the formation of the single correct trail but the development of sensitivity to the multiplicity of routes.

These implications challenge dominant paradigms of assessment and invite a reconception of pedagogical authority. The instructor becomes the *cartographer of desire paths*: observer of emerging trails, custodian of forks, regulator of rhythm, and facilitator of interface transitions.

**Conclusion.** Stigmergy demonstrates that the informal self-organization of students is not random noise but structured emergence. A learning group does not deviate from the route through carelessness—it wears *desire paths* because the designed walkway of the syllabus does not always lead where the group needs to go. Integrated with Eco-Centered Psychological Facilitation and the theory of cognitive interfaces, stigmergy provides both a theoretical and a practical framework for sustaining cognitive interface transitions in higher education.

Learning becomes an ecological event, not a delivery mechanism. The classroom is transformed into a dynamic system in which traces coordinate meaning-making, and facilitation is the art of cartography: the ability to notice trails before they become obvious and to keep forks open longer than is comfortable. The role of AI in this context is not the replacement of the instructor nor the amplification of control, but the extension of the stigmergic field: a digital cartographer who helps render visible trails that are invisible to the unaided eye.

In an era shaped by AI and digital mediation, understanding stigmergy is not an elective interest but a fundamental condition for cultivating sustainable, distributed intelligence capable of navigating uncertainty. The best campuses do not fight desire paths—they observe them and redesign the architecture in accordance with where people actually walk. The best educational systems can learn to do the same.

*Prospects for Further Research.* Future research may pursue the empirical verification of the proposed model using methods of discourse analysis and computational stigmergy, as well as the development of AI-supported tools for stigmergic facilitation.

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