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THE MICROBIOME: PEDAGOGICAL SUGGESTIONS FOR A BIO-EDUCATIONAL DIALOGUE

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Abstract

This paper explores the pedagogical implications of the growing understanding of the human being as a superorganism, a complex ecosystem in continuous interaction with the environment. Based on the scientific evidence on the role of the microbiome in relation to physical and mental health, an epistemological reflection on the nature of pedagogical knowledge is proposed: a "biotic pedagogy" is proposed, attentive to the interactions between body, mind and environment.

Keywords

Biome, Superorganism, Biotic pedagogy, Psychoneuroendocrinoimmunology

1. *The learning superorganism*

The burgeoning field of microbiome research, coupled with the increasing recognition of the human being as a superorganism, presents educators with a compelling impetus for critical reflection. This evolving understanding raises profound epistemological questions regarding the very nature of pedagogical knowledge. Pedagogy, concerned as it is with the processes of learning and the means by which these processes may be influenced through educational interventions, must necessarily acknowledge and accommodate the intricate interactions between the individual and their natural, social, and technological environment.

Drawing on Dorit's (2014) conception of the human body as a complex ecosystem, we adopt the notion of the 'superorganism'. This perspective recognises that the human body plays host to a vast and diverse array of microorganisms (bacteria, fungi, viruses, etc.), residing on the skin, within the mucous membranes, and most notably, in the intestine.

Crucially, the microbiota inhabiting our bodies is not inert; it engages in dynamic interactions with its human host, significantly influencing metabolic processes and, consequently, overall health. Furthermore, emerging research indicates that the microbiota may even exert an influence on behaviour. Studies exploring the gut-brain axis, notably those by Cryan et al. (Cryan & Mahony, 2011; Cryan & Dinan, 2012; Cryan et al., 2019), have demonstrated a compelling link between certain psychiatric conditions and the composition and activity of the microbiota.

The microbiota constitutes a complex ecosystem, existing in a symbiotic relationship with the human host. Its composition and function are influenced by a multitude of factors, including environment, diet, and lifestyle. Notably, the intestinal microbiota can exert a profound influence on brain health. Intestinal inflammation, which may arise from a diet high in sugars, fats, and excessive calories, can disrupt the delicate balance of the microbiota. This disruption, in turn, can lead to the release of pro-inflammatory cytokines by immune cells, which may subsequently reach the brain via various pathways and modulate its activity (Cryan & Dinan, 2012; Mayer et al., 2014; Carabotti et al., 2015; Guillemot, Colomb & Vergères, 2019).

Research indicates that the probiotic strains *Lactobacillus helveticus* and *Bifidobacteria longum* can exert beneficial effects on mood and stress response. Specifically, they have been shown to reduce anxiety, mitigate the physiological response to stress, and improve mood in individuals with irritable bowel syndrome and chronic fatigue, likely due to their influence on cortisol levels (Huang, Wang & Hu, 2016). Furthermore, these probiotics have been found to

increase pain tolerance in individuals experiencing depression and anxiety.

These findings prompt a crucial question for pedagogical theory: how might such scientific insights inform and reshape our understanding of learning? Could the concept of the superorganism serve as an influential metaphor, capable of transforming the epistemological framework of pedagogy?

Anticipating the subsequent elaboration of this theme, I contend that the superorganism concept necessitates a re-evaluation of learning itself. If both body and mind are demonstrably influenced by the microbiota, then learning can no longer be conceptualised as a purely cognitive process. Rather, a comprehensive understanding of learning must incorporate biological and environmental variables.

This, in turn, suggests the validity of an ecological approach to the learner, acknowledging the intricate interplay of body, mind, and environment. The inherent complexity of these interactions underscores the need for personalised educational interventions, tailored to the specific needs of each individual learner, conceptualised as a holistic unit encompassing internal and external factors.

To effectively engage with this holistic unit, educational institutions must cultivate learning environments that prioritise health and well-being, encompassing nutritional considerations and promoting engagement with the natural world. These principles underpin what we propose as a 'biotic pedagogy'.

2. Towards a biotic pedagogy

Credit must be given to Elisa Frauenfelder for advocating what she has defined as a bioeducational approach for pedagogy (Frauenfelder, 2016), which leads teaching actions to adopt enactive perspectives. (Frauenfelder, Santoianni & Striano (2002)). These perspectives assign to teaching-learning activities the function of regulating the subject in search of an effective relationship with the environment. If interactions between the individual and the environment modify its status as a superorganism, educational action is a possible lever for the subject's state of well-being.

The intersection between pedagogy and biological and medical sciences is a need that runs underground in the history of pedagogy. Just think of names such as Jean Itard and Eduard Seguin, who are mentioned in pedagogical textbooks, in the chapter on special pedagogy, as well as in medical textbooks.

In Italy, contributions with a medical-psycho-pedagogical approach were offered during the positivist era by Andrea Verga, Enrico Morselli, Sante De Santis, Giuseppe Montesano and, above all, Maria Montessori. (Campagnolo,1999). And in 1946, with the Psycho-pedagogical Conference in Trezzano, the idea of Medical-Psycho-Pedagogical Centers (CMPP) was launched, which found their first realization the following year with the experiences in Rome directed by Giovanni Bollea and Adriano Ossicini. (Lo Sapio, 2012).

Despite these precedents, the relationship between pedagogy and biomedical sciences was interrupted by the idealist period, which made pedagogy ancillary to philosophy. (Mariani, (2011). Today, a new conception of the human mind, which is studied in relation to the body, revives the relationship between pedagogy and biomedical and neuroscientific sciences.

For a long time, pedagogy adhered to the Cartesian idea that the mind is separate from the body. This led it to focus on the development of cognitive skills, neglecting the motor and affective dimensions of learning. Today, research in the field of neuroscience and the above-mentioned research on the biome impose a new conception of the mind. This is - it is said – “embodied”, “embedded”, “enacted”. As embodied, the mind is in close connection with bodily structures and processes: emotions and actions influence what we think. As embedded, the mind is seen in continuous interactions with the environment - physical, social, technological. This implies that context, interpersonal relationships, and tools decisively influence learning. As enacted, the mind acts in the world, constructing its own reality. Through its experiences, the subject constructs the meanings that guide it in its interpretation of the world.

Pedagogy, understood as a discipline in constant dialogue with biomedical disciplines, can offer new frameworks for learning processes, ways to promote them through new teaching methods, new intervention models for learning disorders, and new organizational formulas for the school institution, so that it can comprehensively promote the health and well-being of students and educators.

Elisa Frauenfelder is credited with advocating for a bioeducational approach to pedagogy (Frauenfelder, 2016), which encourages the adoption of enactive perspectives in educational practice (Frauenfelder, Santoianni & Striano, 2002). These perspectives posit that teaching and learning activities serve to regulate the individual in their pursuit of a harmonious relationship with their environment. If, as posited, interactions between the individual and the environment modify their status as a superorganism, then educational interventions hold the potential to significantly influence an individual's well-being.

The intersection of pedagogy with biological and medical sciences represents a recurring theme within the history of pedagogical thought. Consider, for instance, figures such as Jean Itard and Eduard Seguin, whose work is referenced in both pedagogical and medical texts, particularly within the domain of special education.

In Italy, the positivist era witnessed contributions to a medical-psycho-pedagogical approach from scholars such as Andrea Verga, Enrico Morselli, Sante De Santis, Giuseppe Montesano, and notably, Maria Montessori (Campagnolo, 1999). Subsequently, the 1946 Psycho-pedagogical Conference in Trezzano led to the establishment of Medical-Psycho-Pedagogical Centres (CMPP), with pioneering initiatives launched in Rome under the direction of Giovanni Bollea and Adriano Ossicini (Lo Sapio, 2012).

However, despite these precedents, the relationship between pedagogy and biomedical sciences was disrupted during the idealist period, which subordinated pedagogy to philosophy (Mariani, 2011). Currently, a renewed conception of the human mind, one that acknowledges its embodied nature, is revitalising the connection between pedagogy and biomedical and neuroscientific research.

For an extended period, pedagogy adhered to a Cartesian duality of mind and body, leading to a focus on the development of cognitive skills, often at the expense of the motor and affective dimensions of learning. Contemporary research in neuroscience and the aforementioned studies on the microbiome necessitate a reconceptualisation of the mind as embodied, embedded, and enacted.

As embodied, the mind is inextricably linked to bodily structures and processes, with emotions and actions profoundly influencing cognition. As embedded, the mind is understood as being in continuous interaction with its environment – physical, social, and technological. This implies that context, interpersonal relationships, and tools exert a decisive influence on learning. As enacted, the mind actively engages with the world, constructing meaning through experience.

Pedagogy, conceived as a discipline in continuous dialogue with biomedical disciplines, can offer new frameworks for understanding learning processes, inform the development of innovative teaching methods, provide novel intervention models for learning disorders, and inspire new organisational structures for educational institutions. Ultimately, this interdisciplinary approach can contribute to a more holistic understanding of learning and facilitate the promotion of health and well-being for both students and educators.

3. The contribution of PNEI

Personally, I find the field of study known as PNEI, which stands for Psychoneuroendocrinoimmunology, particularly interesting for the development of a biotic pedagogy. It allows us to look at health and illness from the perspective of the systemic model.

Now, by systemic approach, we mean the ability to frame the complexity of the human body as the result of a multitude of relationships between all its components, organized into subsystems, such as the nervous, endocrine, and immune systems, which produce emergent qualities, among these everything we can call psyche. (Bottaccioli & Bottaccioli, 2017).

From a pedagogical point of view, then, the body appears not only as an expression of biology, but also as the result of a social construction, a "fabrication", in which various practices are involved, of a socio-ritual, linguistic-symbolic and pedagogical nature. All in close systemic connection.

Since we are in a constant relationship with the environment, we are always learning, and educational action is intended to be a deliberate action on the part of a subject who, through targeted actions that we call 'teaching', intends to produce predictable effects in terms of learning.

This action interacts with the self-organizing capacities of the living system, therefore it cannot be explained as a direct cause (teaching) - effect (learning) action. We might say: between teaching and learning lies the superorganism, with all its complexity.

The biopedagogical approach, therefore, urges us to consider the mind as integrated in the body, as an expression of its functioning dynamics, to think about which elements and relationships concur to determine learning, and not to imagine teaching as a direct action of one subject on another, but as a relationship that integrates the environment, in the awareness of what role it plays in the "construction of the body".

When one really learns, there is the involvement of the emotions, of the body as a whole, the cognitive activity is joined by the relationship with others and with the environment. This means that teaching is the ability to weave such a meaningful relationship with the other that it has profound transformative effects.

Of particular relevance to the development of a biotic pedagogy is the field of psychoneuroendocrinoimmunology (PNEI), which offers a systemic perspective on health and illness. A systemic approach, in this context, entails understanding the human body as a complex network of interconnected systems – nervous, endocrine, immune, and so forth – whose interactions give rise to emergent properties, including those we collectively term the psyche (Bottaccioli & Bottaccioli, 2017).

From a pedagogical standpoint, this implies that the body is not solely an expression of biology, but also a product of social construction – a "fabrication" shaped by socio-ritual, linguistic-symbolic, and pedagogical practices, all operating in a dynamic, systemic interplay.

Given our continuous interaction with the environment, learning is an ongoing process. Educational interventions, therefore, constitute deliberate actions undertaken by an educator who, through targeted strategies, aims to facilitate predictable learning outcomes.

However, these interventions interact with the self-organising capacities of the learner, conceptualised as a complex, dynamic system. Consequently, the relationship between teaching and learning cannot be reduced to a simple cause-and-effect model. Rather, teaching and learning are mediated by the complexities inherent in the superorganism.

A biopedagogical approach, therefore, necessitates a conception of the mind as embodied and embedded, an expression of the dynamic functioning of the organism. This perspective encourages us to consider the multifaceted elements and relationships that contribute to learning, and to move beyond a view of teaching as a direct, unidirectional influence exerted by one individual upon another. Instead, teaching is reconceptualised as a relational process that acknowledges the integral role of the environment in the "construction of the body" and, consequently, the mind.

Genuine learning involves the whole person – emotions, cognition, and the body in its entirety – situated within a dynamic interplay with others and the environment. Effective teaching, therefore, entails cultivating meaningful relationships that foster profound transformation in the learner.

We take up the suggestion of Roberto Esposito (2020), who in his text Immunitas suggests that immunology is an important reference value for the social sciences. If read through the eyes of the pedagogue, the text tells us that those who carry out educational work must rid themselves of the illusion that everything can be learned with the tools of didactics. In reality, he must conceive of himself in more ecological terms, as a facilitator of the processes proper to a body-mind that seeks a functional balance with its environment. This means addressing the issue of complexity. Let us adopt the construct as suggested by Edgar Morin.

Morin (1993: 3) writes: "Complex thinking is aware from the outset of the impossibility of complete knowledge: one of the axioms of complexity is the impossibility, even theoretical, of omniscience. Recognition of a principle of incompleteness and uncertainty. Complex thinking is animated by a constant tension between the pursuit of non-parcelled, non-sectoral, non-reductive knowledge and the recognition of the incompleteness and uncertainty of all knowledge. This tension has animated my whole life... My whole life... I have always striven for multidimensional thinking. ...I have always felt that certain profound truths, antagonistic to each other, were complementary to me without ceasing to be antagonistic".

There are three principles that qualify complexity:

a) *dialogical principle*. The dialogical principle is opposed to the dialectical principle. The dialogical principle consists of relating two apparently irreconcilable things and trying to identify the structure that connects them, as Bateson puts it. As others put it, it is about grasping the structural coupling that binds things together in an ecological context.

b) *Principle of recursiveness*. A recursive process links cause and effect, producer and product, structure and superstructure in a dynamic circularity. The principle of systemic regulation applies.

c) *Hologram principle*. According to the hologram principle, systems are the result of subsystems that function internally as a system. A change at the local level produces effects because of the relationships that link all the subsystems and these to the system more comprehensively.

Conversely, changes at the system level inevitably have repercussions at the subsystem level. The hologram principle is present in both the biological and social worlds.

The holographic principle seeks to overcome reductionism, which sees only the parts, so that the whole is merely the additive result of the parts, as well as holism, which gives no value to local phenomena.

Today, to address the serious problems that humanity itself has generated with the advancement of its knowledge, a systemic, ecological thinking is necessary, one that takes into account the complexity of reality and adopts consequent behaviors. In recent times, public perception of the increased risk deriving from reductionism has grown. Classical science has led to an oversimplification, achieving great results by assuming a linear cause-effect relationship, but it has also made us blind to complexity. It is now a matter of reintroducing complexity, and this is the "new holism" we need.

Drawing on the work of Roberto Esposito (2020), who, in Immunitas, posits immunology as a significant reference point for the social sciences, we propose that educators relinquish the illusion of didactic omnipotence. Instead, embracing an ecological perspective, they should reconceptualise their role as facilitators of the processes inherent in a body-mind seeking equilibrium within its environment. This necessitates engaging with the concept of complexity, as articulated by Edgar Morin.

Morin (1993: 3) asserts: "Complex thinking is aware from the outset of the impossibility of complete knowledge: one of the axioms of complexity is the impossibility, even theoretical, of omniscience. Recognition of a principle of incompleteness and uncertainty. Complex thinking is animated by a constant tension between the pursuit of non-parcelled, non-sectoral, non-reductive knowledge and the recognition of the incompleteness and uncertainty of all knowledge. This tension has animated my whole life... I have always striven for multidimensional thinking. ...I have always felt that certain profound truths, antagonistic to each other, were complementary to me without ceasing to be antagonistic".

Three principles underpin this notion of complexity:

(a) The Dialogical Principle: This principle, in contrast to the dialectical, seeks to identify the underlying structure connecting seemingly irreconcilable elements (Bateson, cited in Morin, 1993). It encourages an understanding of the 'structural coupling' that binds entities within an ecological context.

(b) The Principle of Recursiveness: This principle highlights the dynamic, cyclical relationship between cause and effect, producer and product, structure and superstructure, emphasizing the role of systemic regulation.

(**c) The Hologram Principle:** This principle posits that systems are comprised of subsystems that themselves function as systems. Consequently, local changes within a subsystem resonate throughout the interconnected network, impacting the overall system. Conversely, changes at the system level inevitably reverberate throughout the constituent subsystems. This principle, applicable to both biological and social realms, challenges reductionist perspectives that focus solely on isolated components, as well as holistic approaches that neglect local phenomena.

Addressing the complex challenges confronting humanity necessitates a systemic, ecological mode of thought that acknowledges the interconnectedness of reality and informs corresponding action. Growing awareness of the limitations of reductionist approaches, with their emphasis on linear cause-and-effect relationships, highlights the need to re-engage with complexity. This 'new holism' requires an appreciation for the dynamic interplay of systems and subsystems, local and global phenomena, and the inherent limitations of knowledge.

4. Enactive learning

We must be able to understand bodies in the specific, living relationship they have with their environment. The learning subject is not passive, he is capable of looking after himself, of being an

active creator of his own mental and physical states. He must be supported, guided and facilitated in his learning processes, not much more.

We can say that pedagogy has to develop a new concept of the learning body and of the possibilities of facilitating learning processes that are not only cognitive but also involve the body (understood as a super-organism).

This elaboration opens up a new approach to the teacher-learner relationship, leading it towards the idea that the teaching-learning process is an enactive process, i.e. one of mutual regulation through highly articulated forms of two-way feedback. The teaching activity must be measured against the immune processes by which the body not only defends itself from the outside, but also, by defending itself from the outside, constitutes itself as a unique and unrepeatable identity. It is an intrinsic element of such processes.

The concept of enactivism was proposed by the neurobiologist Francisco Varela (Varela, Thompson & Rosch, 1991)) within the framework of neurophenomenology (Varela, 1996).

He believed that the objectivism of Galilean science had now shown all its limits. It is a matter - he said - of finding new models for explaining reality that are capable of holding together the subjective (phenomenological) experience we have of things and of reality as it is returned to us by the application of procedures that objectify phenomena. There is a profound co-implication and co-determination between what appears to be on the outside and what appears to be on the inside.

What exactly does it mean to rehabilitate the subject in the practice of science? The rigid opposition between the objective and the subjective, on which we have drawn the epistemological map of cultural practices, has consolidated dialectical oppositions such as body-mind, inside-outside, etc., which originated in world views and ideological perspectives that were interested in dissociating the individual from his context, differentiating society hierarchically, etc.

These juxtapositions have proved particularly deleterious in the medical field, where there has been an approach to states of health and illness that ends up depriving the sick person of his or her experience and, in many cases, compromising, the very possibility of recovery. Mental states and bodily states cannot but be closely related, even if science is still unable to tell us what the rule is that governs the formation of ideas from changes in the state of matter. Illness may be objectively detectable through the use of increasingly sophisticated diagnostic methods, but it remains a subjective experience that the subject can describe in terms of experience. This will certainly correlate with the objective description, even if we do not really know the law that governs this correlation. Nor will it probably be possible to arrive at a deterministic formulation of this law, even as knowledge grows, because the human body (conceived as a mind-body unit) is, in von Foerster's words, a "non-trivial machine", i.e. a machine that responds to the laws of complexity (von Foerster 1970, 2003).

The discourse is transferable to the pedagogical sphere: subjective and objective perspectives must complement each other. Behind the apparent heterogeneity of body and mind, one must be able to discern the profound unity of body and mind, which is possible through the notions of "emergent property" and "self-organisation": consciousness is an emergent property deriving from a physical-neural basis, learning is not only a mental fact, it necessarily involves the systemic balances of the body. Every manifestation during the learning process is a particular way of manifesting the mind-body unity.

An objectivist approach makes the possibility of learning strictly dependent on the teacher's intervention, whereas a more enactivist approach considers learning as the result of the process through which the subject makes sense of the world. Therefore, it is essential to capture the experiences, i.e. the representations of the learner, they become integral elements of the teaching-learning process (Manfreda 2023).

This difference in approach is particularly evident in the case of rehabilitation, where the subject has to recover mental abilities impaired by more or less severe brain damage. Compared to traditional approaches, those that take into account the subject's experience when performing psychomotor exercises are much more effective. This is, for example, the approach of Carlo Perfetti, the founder of neurocognitive rehabilitation (Colazzo 2009).

If the symptom (or sum of symptoms) is a manifestation of a systemic disorder, the Varelian principle of mutual co-determination between the local and the global applies. It was observed that

some epilepsy patients, who had been implanted with electrodes in their brains to analyse the moments before a seizure and predict its onset, were able to "govern" the onset of the seizure if they engaged in cognitive activities with a specific purpose when the first signals sent by the electrodes appeared. This means that an intervention on the psychic dimension, together with other interventions, as part of a multidisciplinary approach to the problem, aimed at regulating his immune system, can certainly enable him to manage his symptoms much better.

In order to act on learning, we need to work on the relationship between the subject and the context, on the subject's relationship with himself and with others. Our experience teaches us that forms of teaching-learning that are oriented towards probing and re-orienting the relational life of subjects help them to overcome learning blocks.

It is essential to understand individuals within the dynamic interplay between their embodied selves and their environment. Learners are not passive recipients of knowledge, but active agents capable of shaping their own mental and physical states. Thus, the role of the educator is to support, guide, and facilitate learning processes, rather than to impose knowledge.

This necessitates a reconceptualisation of the learning body and its potential within pedagogical theory. Learning encompasses not only cognitive processes, but also involves the body as a superorganism, inextricably intertwined with its environment.

This perspective leads to a reimagining of the teacher-learner relationship, wherein the teaching-learning process is understood as an enactive process of mutual regulation, characterised by dynamic, two-way feedback. Teaching, then, should be considered in light of the immune processes through which the body defends itself against external threats while simultaneously constructing a unique identity.

The concept of enactivism, as proposed by neurobiologist Francisco Varela (Varela, Thompson & Rosch, 1991) within the framework of neurophenomenology (Varela, 1996), challenges the limitations of Galilean objectivism. Varela advocated for explanatory models that bridge subjective (phenomenological) experience and objective observations, recognising the profound co-implication and co-determination between the internal and external worlds.

Rehabilitating the subject within scientific practice entails challenging the rigid objective-subjective dichotomy that has shaped epistemological frameworks and led to artificial distinctions between mind and body, inner and outer worlds. These dichotomies, rooted in ideologies that sought to separate the individual from their context, have proven particularly detrimental in the medical field, where they can contribute to a depersonalisation of illness and hinder recovery.

While sophisticated diagnostic methods can objectively detect disease, illness remains a subjective experience. Mental and bodily states are inextricably linked, although the precise mechanisms governing their interaction remain elusive. Even with advances in knowledge, a deterministic understanding of these processes may prove impossible, as the human body, conceived as a mind-body unit, operates as a "non-trivial machine" subject to the laws of complexity (von Foerster, 1970, 2003).

These insights are readily transferable to the pedagogical domain. Subjective and objective perspectives must be integrated, recognising the inherent unity of mind and body. Consciousness, an emergent property arising from a physical-neural basis, and learning, a process that engages the systemic balance of the body, underscore this unity.

An objectivist approach views learning as primarily dependent on teacher intervention, while an enactivist approach emphasizes the learner's active role in constructing meaning. Capturing the learner's experiences and representations becomes crucial to the teaching-learning process (Manfreda, 2023).

This distinction is particularly evident in rehabilitation, where individuals strive to recover mental abilities compromised by brain injury. Approaches that incorporate the subjective experience of the learner, such as the neurocognitive rehabilitation model developed by Carlo Perfetti (Colazzo, 2009), have proven more effective than traditional methods.

Varela's principle of mutual co-determination between the local and the global is exemplified in cases where epilepsy patients, through cognitive engagement, can influence the onset of seizures detected by implanted electrodes. This highlights the potential for interventions that address both the psychological and physiological dimensions of

health, promoting self-regulation and symptom management.

Effective pedagogical practice requires attention to the dynamic interplay between the individual and their environment, encompassing their relationships with themselves and others. Teaching-learning approaches that explore and reorient these relationships can facilitate the overcoming of learning obstacles.

5. Ecosystem learning

The enactive conception therefore invites us to consider the ecosystemic dimension whereby every living being inhabits an environment with which it is in continuous exchange in order to dynamically maintain its identity. As far as the human being is concerned, this means introducing the reality of culture which, acting on the environment, modifies it to adapt it to human needs.

The environment we deal with, the environment that contributes to our constitution, is manipulated by us, so we ourselves generate the system of constraints in which we act. However, since the environment we inhabit is also the environment we share with other living beings, we modify the conditions of existence of all ecosystems.

This is something we have to come to terms with: when our impact on the environment becomes particularly incisive and profound, due to fully deployed technology, all of the planet's arrangements are profoundly altered, to the point that scientists have proposed to consider the inauguration of a new geological era: the Anthropocene (Crutzen & Stoermer, 2000).

So far, changes made to the environment have been driven by the need to satisfy needs in an immediate and direct way, disregarding the ecosystemic consequences and the resulting impacts on other living beings and ourselves. Today, we realize the necessity of broadening our perspective, thinking in terms of systemic relationships.

An example comes from architecture. Some architects, such as Beatriz Colomina and Mark Wigley (2016), promote *biotic architecture*: they argue that buildings should be porous systems, allowing plants and animals to enter our homes. In this debate, our own Stefano Boeri (2014, 2015) has authoritatively contributed.

Until now, architecture has had an immune, i.e. defensive, approach (Forty, 2000)), dominated by the martial metaphor of medicine, favoured by the spread of antibiotics, which, however, have trained microbes to be resistant (so bacteria also learn), bypassing the defences imagined by pharmacology, which now admits the futility of this approach and promotes new therapeutic models (Davies & Davies, 2010).

Buildings have generally been designed to isolate individuals from the outside; environments have been imagined as aseptic to avoid contact between their inhabitants and bacteria and viruses. According to proponents of biotic architecture, it is essential to overcome the antibiotic conception of architecture, as it has contributed to the reduction of human microbiome diversity, with a progressive increase in metabolic diseases and autoimmune disorders.

We need a new way of designing that reconnects us with the rest of the living world. We are a super-organism, so antibacterial architecture is anti-human. We need to reconsider the concepts of protection, comfort and care. We need a design that takes into account the health of our gut, a place of coexistence, according to the logic of the ecosystem.

Biotic architecture should be juxtaposed with biotic pedagogy, that is, pedagogy that conceives of the mind as embodied, extended, embedded, enactive; that knows how to have a different relationship with errors, being able to understand their adaptive function; it enables the intuitive dimension, where decisions derive from the analysis of small data samples, so that the resulting reality becomes a confirmation or disconfirmation of the hypothesis from which the decision matured, acting as feedback that induces rapid modifications and realignments of actions, using technologies as extensions of the mind's potential, others and AI; it does not believe that there is only one solution to solve a problem, but rather encourages the multiplication of potential solutions; it promotes situated learning, knowing that even small context modifications necessitate the development of creative solutions; it teaches people to trust their bodily messages in interacions with others and situations, as studies on the gut teach us that we have a second brain located in our belly (Gershon, 1998). But not only that: in the gut, we have an extraordinary machine that protects us from diseases: 80% of all human cells capable of producing antibodies are located in

the intestinal mucosa, and the intestinal mucosa (Mowat, 2003)), if "unrolled", is the size of the first floor of a villa: 250-300 square metres (Helander & Fändriks,2014).

This connection between the gut and the overall health of the organism was intuitively understood by mankind very early: in fact, in all ancient medical traditions, in the East as well as in the West, the use of plants and other natural substances to "drain" the digestive organs (such as the liver) and the gut is a mainstay of therapy for various types of diseases (from hypertension to dermatitis to inflammations located in different parts of the body).

Today, we know that the ancient practice of treating the belly to positively influence the entire organism has a scientific basis, which is precisely the action of the mucous membrane immune system that has its fundamental portion in the belly.

Biotic pedagogy is the pedagogy of ecosystemic relationships, so it will intervene with all the actors involved (directly, but also indirectly) in the relationship, whose exchanges constitute the context, which properly acts on learning, regulating it. Ultimately, it becomes the design of environments and through this it contributes to the realisation of its purpose. Teaching, as it has long been understood, is, from this perspective, outdated.

The cultural shift is from a paradigm in which the relationship that educates is that between a teacher and a learner, to a paradigm that sees the individual embedded in an environment with which they maintain continuous relationships. The subjective experience of the learner becomes fundamental, since it is that experience that must be considered to help them evolve. Ultimately, it is about encouraging the individual to become more self-aware, learning to self-educate.

No one can really teach anything to anyone, as everyone learns what they consider integrable to their self.

The enactive perspective compels us to consider the inherent ecological embeddedness of living beings, who exist in a state of continuous exchange with their environment to dynamically maintain their identity. For human beings, this necessitates acknowledging the role of culture, which mediates our relationship with the environment, shaping it to meet our needs.

The environment we inhabit, and which contributes to our constitution, is subject to our manipulation. Thus, we actively participate in generating the constraints that shape our existence. However, this manipulation extends beyond our immediate needs, impacting the wider ecosystem we share with other organisms.

The profound impact of human technology on the planet has led scientists to propose the designation of a new geological epoch: the Anthropocene (Crutzen & Stoermer, 2000). Historically, environmental modifications have prioritised immediate human needs, often disregarding the broader ecological consequences for ourselves and other species. Today, a growing awareness of systemic interconnectedness necessitates a shift towards a more holistic perspective.

This shift is evident in the field of architecture, where proponents of biotic architecture, such as Beatriz Colomina and Mark Wigley (2016) and Stefano Boeri (2014; 2015), advocate for buildings as porous systems that integrate with the natural world. This challenges the prevailing "immune" or defensive approach to architecture (Forty, 2000), which, influenced by the martial metaphors of medicine and the widespread use of antibiotics, has sought to create aseptic environments that isolate humans from the microbial world.

However, this approach, with its emphasis on sterilisation, has inadvertently contributed to a reduction in human microbiome diversity, potentially leading to an increase in metabolic diseases and autoimmune disorders. Biotic architecture, conversely, promotes a reconnection with the living world, acknowledging our inherent nature as superorganisms. It necessitates a re-evaluation of concepts such as protection, comfort, and care, prioritising the health of our microbiome and recognising the built environment as an integral part of the ecosystem.

This philosophy extends to the realm of education, where a biotic pedagogy embraces the notion of the embodied, extended, embedded, and enactive mind. This pedagogy values errors for their adaptive function, cultivates intuition, and leverages technology, including AI, as an extension of human potential. It encourages the exploration of multiple solutions, promotes situated learning that responds to contextual nuances, and fosters trust in bodily signals and intuition. Crucially, it acknowledges the gut-brain axis, recognising the gut as a "second brain" (Gershon, 1998) and a vital component of our immune system (Mowat, 2003; Helander & Fändriks, 2014).

This understanding resonates with ancient medical traditions that intuitively grasped the connection between gut health and overall well-being. Modern research confirms the scientific basis of these practices, highlighting the crucial role of the gut in immune function.

Biotic pedagogy, therefore, is a pedagogy of ecological relationships, acknowledging the interconnectedness of all actors within the learning environment. It prioritises the design of environments that support learning, moving beyond traditional conceptions of teaching as a direct transmission of knowledge. This represents a paradigm shift from a teacher-centric model to one that recognises the learner's embeddedness within a dynamic ecosystem. The subjective experience of the learner becomes paramount, guiding their evolution towards greater self-awareness and self-directed learning.

Ultimately, this approach acknowledges the limitations of didactic instruction, recognising that true learning is a process of integration and self-construction.

6. Conclusions

Starting from the concept of man as a learning super-organism, the outlines of what has been defined as biotic pedagogy, in analogy to biotic architecture, we have examined the scientific evidence on the role of the human microbiome, proposing, on this basis, complex epistemological. Starting from the concept of man as a learning super-organism, the outlines of what has been defined as biotic pedagogy, in analogy to biotic architecture, we have examined the scientific evidence on the role of the human microbiome, proposing, on this basis, complex epistemological reflections on the nature of pedagogical knowledge and its history. In this context, we have highlighted Elisa Fauenfelder's pioneering contribution and introduced the construct of “enactive learning”, which entails a concept of teaching as a function of regulating the individual in his interaction with the environment.

We have turned our attention to the PNEI, an approach to the study of the human body that is fully in line with the assumptions of a pedagogy attentive to complexity, which assumes both the specificity of psychic functioning and its nature as a quality resulting from the interactions between the subsystems (nervous, endocrine, immune) that regulate life processes. At this point we have introduced the immune metaphor, which encourages the pedagogue to free himself from the illusion of omnipotent teaching and instead frames him as a facilitator of the processes of a body-mind seeking a functional balance with the environment. Biotic pedagogy, which formulates its principles on the basis of this theoretical background, is thus configured as a pedagogy of the ecosystemic relationship, which considers the body as an expression of biology and, at the same time, as a social construction, shaped by socio-ritual, linguistic-symbolic and educational practices.

Grounded in the conception of the human being as a learning superorganism, this paper has explored the contours of a 'biotic pedagogy', drawing parallels with the principles of biotic architecture. We have examined the scientific evidence concerning the role of the human microbiome, proposing, on this basis, a complex epistemological framework for understanding pedagogical knowledge and its historical development. Within this framework, we have highlighted the pioneering contribution of Elisa Frauenfelder and introduced the construct of "enactive learning," which entails a conception of teaching as a regulatory function that facilitates the individual's interaction with their environment.

Furthermore, we have directed our attention to psychoneuroendocrinoimmunology (PNEI), an approach to the study of the human body that aligns with the tenets of a pedagogy attentive to complexity. PNEI acknowledges both the specificity of psychic functioning and its emergent nature, arising from the interplay of the nervous, endocrine, and immune systems that regulate life processes. In this context, we have introduced the immune metaphor, which encourages educators to relinquish the illusion of didactic omnipotence and instead adopt the role of facilitators who support the individual's pursuit of a functional equilibrium with their environment.

Biotic pedagogy, informed by this theoretical foundation, emerges as a pedagogy of ecological relationships. It considers the body as both an expression of biology and a social construct, shaped by a dynamic interplay of socio-ritual, linguistic-symbolic, and educational practices.

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