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Conceptual Article

Nested ecologies of childhood: A microbial turn in developmental theory

Zsuzsa Millei[1], Nick Lee[2], Sarah Alminde[3], Asta Breinholt[4], Mira Grönroos[5], Riikka Hohti[6], Sami Keto[7], Marja Roslund[8], Spyros Spyrou[9], Tuure Tammi[10], Hanne Warming[11], Juliene Madureira Ferreira[12]

Abstract: This article expands Bronfenbrenner's bioecological model by integrating biological and ecological processes—particularly microbial life—into its core concept of proximal processes. Drawing on host–microbiome research and the concept of the child-as-ecosystem, we reconceptualize the developing person as a multispecies being embedded within nested ecological systems. Through four interdisciplinary encounters—spanning social stratification, family separation, socialisation, and environmental health—we demonstrate how microbial diversity and ecological entanglements shape children's development, well-being, and learning. We argue that BEM's human-centered framework must evolve to reflect multispecies interdependencies and ecological realities, especially in the context of biodiversity loss and climate change. This rethinking has direct implications for early childhood education, research, and policy, offering a more ecologically attuned model of development.

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Introduction

Bronfenbrenner's (Bronfenbrenner, 1979) ecological model of child / human development is a key theory that addresses the process of development in interaction with the environment and within a series of nested environmental systems. Bronfenbrenner's theory has been highly influential in early childhood education. Its first major application was in the Head Start program, which shifted focus away from deficit-based explanations for marginalized children's educational outcomes, toward understanding the broader systemic influences on development. It has shaped Early Development Indexes and informed program planning globally for infants and toddlers by promoting a holistic view of the multiple systems and interactions that impact early development (Elliott & Davies, 2018). Just a basic search on the theory and early childhood education brings up hundreds of results, addressing global and local policy for young children, themes of family involvement, early childhood environments, inclusive practice, communities, collaboration, impact of Covid19 and so on. Since its introduction in 1979, Bronfenbrenner's ecological systems model has been widely used in early childhood education, offering an innovative child-centred approach and a focus on real life environments. However, despite its use of the term "ecological," the model primarily addresses human-centered social systems and interactions, overlooking children's interdependence with nonhuman and material elements (Elliott & Davis, 2018; Logan & Widdop Quinton,

[1] Tampere University, Faculty of Education and Culture, Tampere, Finland, e-mail: Zsuzsa.Millei@tuni.fi, ORCID: https://orcid.org/0000-0003-4681-6024
[2] University of Warwick, Education Studies, Coventry, United Kingdom, e-mail: n.m.lee@warwick.ac.uk, ORCID: https://orcid.org/0000-0002-6040-9030
[3] Roskilde University, Department of Social Sciences and Business, Roskilde, Denmark, e-mail: sararas@ruc.dk, ORCID: https://orcid.org/0000-0002-6830-4815
[4] Roskilde University, Department of Social Sciences and Business, Roskilde, Denmark, e-mail: astab@ruc.dk, ORCID: https://orcid.org/0000-0002-4706-8470
[5] University of Helsinki, Ecosystems and Environment Research Programme, Helsinki, Finland, e-mail: mira.m.gronroos@helsinki.fi, ORCID: https://orcid.org/0000-0002-8210-8837
[6] University of Helsinki, Department of Education and Practical Theology, Helsinki, Finland, e-mail: riikka.hohti@helsinki.fi, ORCID: https://orcid.org/0000-0001-6731-589X
[7] Tampere University, Faculty of Education and Culture, Tampere, Finland, e-mail: sami.keto@gmail.com, ORCID: https://orcid.org/0000-0002-6055-190X
[8] Natural Resource Institute Finland, Helsinki, Finland, e-mail: marja.roslund@luke.fi, ORCID: https://orcid.org/0000-0002-3153-7375
[9] European University Cyprus, Social and Education Sciences, Nicosia, Cyprus, e-mail: S.Spyrou@euc.ac.cy, ORCID: https://orcid.org/0000-0003-0493-1403
[10] University of Oulu, Faculty of Education and Psychology, Oulu, Finland, e-mail: tuure.tammi@oulu.fi, ORCID: https://orcid.org/0000-0002-7582-8887
[11] Roskilde University, Department of Social Science and Business, Roskilde, Denmark, e-mail: hannew@ruc.dk, ORCID: https://orcid.org/0000-0003-2212-8876
[12] Tampere University, Faculty of Education and Culture, Tampere, Finland, e-mail: juliene.madureiraferreira@tuni.fi, ORCID: https://orcid.org/0000-0002-8977-5982

Corresponding author: Zsuzsa Millei

2018). There have been previous moves to include an ecological dimension into development models, such as Stanger (2011), who advocated for integrating true ecological thinking into developmental theory—emphasizing the complex interrelationships that sustain living systems. Moreover, he called for including humans and the physical/natural environment at every system level and introduced a nanosystem to account for ecological processes beyond human perception. In this article, we follow these initiatives and continue to add considerations of ecology to the model.

Bronfenbrenner continuously developed his views on human development and arrived at the new *bioecological model* later in his life to study human development over time with its four defining properties: *(1) Process, (2) Person, (3) Context, and (4) Time*. At the core of this model is the interaction between the individual and the environment (*Process*) which entails *proximal processes* that produce development over time. The effect *proximal processes* have on the developing person depends on how regularly they occur and on the "characteristics of the developing *Person*, of the immediate and more remote environmental *Contexts*, and the *Time* period in which the proximal processes take place (Bronfenbrenner and Morris, 2007, p. 795, original emphasis). Importantly, the characteristics of the *Person* may have biological origins. Bronfenbrenner (1979) addressed the role of organic biological factors and emphasized the dynamic interplay where these biological characteristics interact with and are mediated by the ongoing reciprocal interactions within the individual's immediate environment over time. The biological factors were, however, attributed to human behaviors, attitudes, emotions, motivations, and genetics, which is affected (transformed) in *Processes,* more concretely as epigenetics, and did not include broad ecological dimensions. Epigenetics is where person and environmental interactions of proximal processes are observed in genes and environments that "work together to produce functional organisms" in which signals from the environment activate DNA (Gottlieb, 1998, p. 792). Thus, while the environment is present in two-way interactions between the *Person* and her environment, the environment is only considered as it interacts with genetics. Within *Processes* we can see the dynamic characteristic of development in the mutual constitution of individual and environment – it is not just the individual that is affected by *proximal processes*, but the way the individual actively engages with(in) the environment also affects it. Thus, the richness of this model is in the notion that "form, power, content, and direction of the proximal processes affecting development vary systematically as a joint function of the characteristics of the developing person, the environment—both immediate and more remote—in which the processes are taking place" (Bronfenbrenner and Morris, 2007, p. 798). Yet still, the environment is not conceptualised in ecological terms.

In this article, we expand Bronfenbrenner's bioecological model (BEM) by integrating ecological and biological processes into *proximal processes*. Specifically, we propose including enduring relationships with non-human beings—such as the microbiome—as constitutive of both the individual and ecology. Drawing on host-microbiome research (e.g., McFall-Ngai, 2017; Margulis & Sagan, 2002), we reconceptualize the person as a multispecies organism in symbiosis with its surroundings. This perspective highlights microbial diversity as central to development and well-being, linking individual lives to broader ecological systems and biodiversity loss (Haahtela et al, 2019). We argue that including microbial interactions as part of *proximal processes*, demand attention to biological and ecological entanglements in child development, everyday childhood practice, research and policy.

Therefore, our first aim is to report on a range of distinct ways of encountering BEM and our expanded formulation of the *Person* - child-as-ecosystem - we coined using host-microbiome research (see Millei et al., 2025). Encounters range from treating host-microbiome data as information that can simply be factored into appropriate aspects of BEM to seeing ecology as encompassing all organisms, inclusive of Persons, living on the planet and thereby casting BEM as in need of a fundamental change. Our second aim is to connect microbiology and ecology with BEM as well as to highlight the interconnected changes undergoing between microbial and planetary processes. Therefore, this paper adopts a theoretical and interdisciplinary methodology, drawing on biological and social disciplines to stage four encounters between the bioecological model and the child-as-ecosystem in intersection with host-microbiome research. We critically engage with existing literature for this work rather than offering an empirical analysis.

In what follows, we will first present the concept of the 'child-as-ecosystem' detailing the current research contexts that have informed our development of it and pose some questions regarding the biological in BEM with an intention to add to the model. We ponder on whether the model can be adapted to include the most significant features of the child-as-ecosystem and whether, and in what ways, the figure of the child-as-ecosystem exceeds the terms of the bioecological model. The task of drawing more of the living world into the frames of reference of childhood research is at once promising and disorienting. We argue that it is more urgent than ever due to rapid environmental changes. Our intention is not to settle the questions we raise, but to explore possible responses, and to do so in the hope of engaging others who are also trying to orient themselves toward childhoods and development within our rapidly changing world.

The 'Child-as-Ecosystem' and Multispecies Ecology

In early education, psychology, social work and childhood studies biological knowledge is often presented as necessary to better understand child development and wellbeing, children's agency, socialization, and learning (e.g. Gabriel, 2021; Tatlow-Golden and Montgomery, 2021). The need for a unifying perspective of biological processes and knowledge (Prout, 2005) and their 'biosocial' connection with social theories and social relations has been raised earlier by Prout (2005), Lee (2013), and Ryan (2012). Such concerns with ontology may enhance theoretical and methodological developments that foster transdisciplinary study of childhoods (Alanen, 2017; Stryker et al., 2019). In childhood studies, there are also connecting concerns about biodiversity loss, climate change and children's wellbeing which have been raised first by Garbarino (1993, p. 179), who illuminated our 'bifocal vision, focused either on immediate child and family issues or on long-range environmental issues'. However, despite the calls for a biosocial perspective and unified vision in childhood studies and early childhood education that also brings concerns about the planetary health and childhood, it seems we have mostly kept issues of child development distanced from issues of biodiversity and climate crises. *Can host-microbiome research with its emphasis on biology and multi-scale relations between organisms and planetary processes offer a unified vision? How could this different focus on the biological together with the environmental be incorporated within Bronfenbrenner's bioecological model, if at all?* We seek to answer these questions in three subsections, in subsection A, we consider microbes as part of human ecologies and thus directly implicated in *proximal processes* and developing Persons; in subsection B, we expand our vision to ecology; and in subsection C, we consider what an attention to microbes means regarding the bioecological model's defining properties.

Sub-section A: Child-as-Ecosystem

According to host-microbiome research, the human as an organism has a biological / microbial constitution. This organism consists of human cells and a vast number of microbial organisms, such as bacteria, fungi or protozoa that outnumber human cells. Thus, the human can be considered as an ecosystem and is located within nested ecosystems (Margulis and Sagan, 2002, p. 86). The notion of an ecosystem moves us directly into the biological complexities and relationalities of different organisms. The human-as-ecosystem is not a homogenous unity of one species. It is a biosocial being, a member of a collective (Costello et al., 2012). It is mutually entangled in a human-microbial ecosystem where the diversity of this ecosystem is the key to health, im/balance, competition and change, reflective also of the large-scale need for the diversity of living and life processes on the planet. The view of the human body as an ecosystem necessitates an understanding of how a developing child co-exists and co-evolves with microbes internal and external to all bodies in multiple, interdependent ways so that "the loss of a single species probably entails the loss of many kinds, not just one" (McFall-Ngai, 2017, p. 66).

With the concept of the child-as-ecosystem, we see possibilities for creatively rethinking the child in ways that disrupt human-centered and exceptionalist understandings acknowledging the radical interdependence of all life in which human bodies, microbes and genetics are amongst the constitutive elements. It also moves a further step in reconceptualizing ontology by seeing the child not as an external addition to the world but as already part of unfolding bioecologies. More importantly, the child's body is

itself a multiplicity which springs from the largely symbiotic relationalities in place within the multiple ecosystems and opens our thinking to different kinds of relation making, research and practices.

Research shows that the host-microbiome-ecology connection is not inconsequential, but a fundamental prerequisite for what we may call human life and development (e.g., Blaser, 2016; McFall-Ngai, 2017). With the recognition of these relations, we can elaborate on the idea of how the microbial life add to what is considered in proximal processes in BEM and with what consequences for conceptualizing development. Particularly, in calling attention to new relations, we must pay attention to the Person as a multitude in synergistic (symbiotic) relations within nested ecologies.

Recognizing microbial life also emphasizes how numerous mutually defining social and biological processes can lead researchers to ask different questions and bring into view relations perhaps less seen or explored before (see more in Lee, 2013). We are also inspired by what such a recognition may mean for development and a child's emerging relations with the world—their living conditions, relation-making practices and the ethics and politics which such understandings and practices may ignite. We consider the potential for reimagining the Person / child within this more expansive and relational frame promising, though we do realize that this is also a frame which has yet to gain traction in academic circles, in policy and certainly in public discourse.

Sub-section B: Bioecology

To enable the addition of life processes to BEM, we present an account of ecology, a concept and a research field which studies the interactions among individuals, species and the environment. At a very fundamental level, ecology is the composition and diversity of species that are based on four processes: dispersal, selection, diversification and drift (Nemergut et al., 2013; Vellend, 2010). First, organisms arrive via dispersal, migrating from the regional species pool in the surrounding environment, which differs across locations. For example, in rural areas microbial diversity is generally higher compared to urban areas (Parajuli et al., 2018) which is likely to affect dispersal of environmental microbes in homes (Grönroos et al., 2024). Also, human and non-human animal contacts contribute to the regional species pool of microbes by introducing their own individual microbial species into the potential collection of dispersers (Song et al., 2013).

Second, the process of selection occurs when species' features vary, thus resulting in species varying in fitness under different circumstances, for example, under different levels of resource availability or presence of other species. One realization of resource availability is the effect of host diet on gut microbial composition (Wilson et al., 2020). For instance, different types of fibers are broken down by different bacterial species, and thus the fiber content of the diet selects certain types of bacterial species (Cronin et al., 2021). An example of species' interactions is colonization resistance. Microbial species can inhibit the growth of other species through interference competition (e.g. producing inhibitory compounds) or exploitative competition (e.g. consuming nutrient resources) (Caballero-Flores et al., 2023). These are some of the mechanisms through which diverse microbial communities decrease the risk that pathogenic microbial species gain dominance and cause diseases.

Third, in addition to dispersal, new species and forms appear also via diversification. In asexually reproducing organisms, such as bacteria, even one favorable mutation may lead to the development of a new strain with novel functions (Nemergut et al., 2013). One example of diversification is the appearance of antibiotic-resistant bacteria which are a severe problem affecting children especially in low-income countries (Larsson and Flach, 2022).

The fourth process is called drift (Vellend, 2010). Even if conditions favor a certain species, there is some possibility that this species will drift to extinction. Small population size increases the importance of drift. A typical characteristic of human microbial communities is the high number of microbial species that are present in low abundances thus being vulnerable to random extinctions (Fodelianakis et al., 2021).

These four processes act simultaneously, but their relative strength varies under different scenarios. For example, children born via caesarean section, are mainly colonized by the mother's skin microbes

instead of vaginal microbes (Sprockett et al., 2018), and an imprint of this different community composition can be seen even two years after birth (Bokulich et al., 2016). One potential reason for this difference is the priority effect which means that history affects the other processes: dispersal, selection, diversification and drift (Sprockett et al., 2018). When priority effects occur, the order of arrival (dispersal) affects the resulting community composition, including selection, diversification and drift.

Adding understandings of bioecology as related to host-microbial relations to BEM broadens the four properties —Person-Process-Context-Time— and the synergistic relationships between Persons and Contexts. The Person is then composed of dynamic and constantly evolving bioecological (microbial) relations constituted by external biosocial relations and internal ones and their synergistic relations within nested ecosystems. These biological and ecological relations are often obscured by assumptions that the child is a unified human subject and that human biological processes are universal (Lee, 2013). The integration of microbial relations which we demonstrated here into BEM, which already assumes varied biological processes, can open BEM for reconsidering child development and the child's relations with ecologies as emerging in synergistic relations between bio-ecological and social, societal and historical processes. Our proposal enlarges the model as it adds one specific connecting system that is simultaneously in Person and Context, bringing focus to the systemic complexity involving the biological in BEM's model.

Sub-section C: Synergistic Relations

When considering an organism and its development from a multispecies framework, mutually affecting relations with other organisms as well as natural, cultural, economic, political and technological forces are considered important. The Person's context becomes

> the multitudes of lively agents that bring one another into being through entangled relations […] These larger contexts are […] complex "ecologies of selves," dynamic milieus that are continually shaped and reshaped, actively—even if not always knowingly—crafted through the sharing of "meanings, interests and affects," as well as flesh, minerals, fluids, genetic materials, and much more." (van Dooren et al., 2016, pp. 3-4)

Taking the more-than-human seriously – assemblies of other animals, plants, fungi, microbes, but also chemicals (e.g., acids) and inorganic matter (e.g., salt, rocks, metals) – calls for a notion of development that is necessarily 'developing with' whereby one becomes different through others becoming different. Multispecies studies often call for tracing heterogeneous assemblages to consider what is at stake for those involved. Whose births, bonds and growing up matter and how, for instance (Tammi et al., 2023)? What are 'we' to a myriad of others? Bronfenbrenner certainly presents proximal processes as synergistic interactions, but as interactions between somewhat isolated objects, and the focus of investigation remains on the human. This is a point of difference with multispecies vision as coined by van Dooren and colleagues (2016). The notion of 'developing with' refers to 'intra-action' where synergistic relations change the so called 'objects' as well and this needs far more attention than usually given. Gottlieb's work (1998) which has been incorporated to BEM also highlights environmental influences in the ways DNA information structures proteins and organisms, and thereby identifies a mechanism through which environmental changes in the form of, for example, temperature, light-dark cycle, or presence of food are registered in development as differences in the Person from the molecular scale up to behavior that can go on to affect the environment over time. BEM's Time property considers time as "continuity versus discontinuity in ongoing episodes of proximal process" and "periodicity of these episodes across broader time intervals, such as days and weeks" as well as "changing expectations and events in the larger society, both within and across generations, as they affect and are affected by, processes and outcomes of human development over the life course" (Bronfenbrenner and Morris, 2007, p. 796). A notion of linear time is at the heart of these considerations that sits uncomfortably with even Gottlieb's (1998) description of environmental changes that refer to circularities. Led by these brief considerations, multispecies childhood studies could help in re-signifying Bronfenbrenner's anthropocentric and interactional model in the era of biodiversity loss. Its ontology pushes against human exceptionalism by highlighting a specific type of synergistic relation with changing environments: intra-action with/in the bioecological environment which humans are entangled with and nested and synergistically interdependent on its broader life processes. An alternate possibility is to take the human Person momentarily out of focus and give attention to a world of beings

'made in entangling relations with significant others', as Anna Tsing (2013) defines 'social', where the social includes also more-than-human socialities, such as animal, plant or microbial community collectivities or bioecologies. Then, would we, through blurring the human, actually gain a sharper view of what it means to be and develop as a human?

Either way, to recognize more life processes and their multi-scale synergistic relations within the planetary context, the understandings of human and other organisms must take place as multispecies worlds, to include ecologically embedded views. This would offer a way to understand proximal processes as dependent on, entangled with and reliant on ecologies which are increasingly threatened today and the development of which needs parallel attention to that of human development. In the following section, we illustrate and reflect on the points we made above as we present four encounters with the BEM in relation to our disciplinary fields.

Research Based Encounters with BEM

Each of the following encounters draws on existing research relating BEM and 'child-as-ecology' in a distinctive way. Each encounter introduces a different field of expertise - Encounter 1, social stratification; Encounter 2, child and family social work; Encounter 3, educational phenomenology; and Encounter 4, environmental ecology and health. To conclude each encounter, we reflect on BEM and the life processes that the encounter draws attention to.

Encounter 1: Ecology of Living Space and Proximal Processes

In BEM, proximal processes are synergistic relationships between the Person and Context (Bronfenbrenner & Morris, 1998, p. 996), which could take place, for example, in shared parent-child or child-child activities, group play and individual play (Bronfenbrenner and Ceci, 1994). Shared parent-child activities are socially stratified, with socioeconomically advantaged families spending more time in developmentally tailored play and teaching than less advantaged families (e.g. Kalil et al., 2012) making these proximal processes a key mechanism of social reproduction. Likewise, the physical surroundings and ecologies of proximal processes are also shaped by the child's socioeconomic status. Hence, the relationship between the child's ecological environment and socioeconomic status is one of the new connections between the biological and the social that we wish to highlight here. In picturing a child and a parent playing or reading together, what might the surroundings look like? Proximal processes might take place in a multitude of sites including human-built environments and green spaces where in both the notion of the child-as-ecosystem directs attention to the ecological environment and the microbial life in that environment. Specifically, it raises attention to how the microbial life of the ecological environment affects proximal processes.

The relationship between the brain and the gut is important to consider in the above social relationships which are partly governed by the gut-brain-axis. In a reciprocal relationship, the brain affects intestinal activities and the gut affects mood, cognition, and mental health (e.g., Appleton, 2018). Socioeconomic status influences accessibility to physical spaces which are characterized by different microbial diversity. While studies show that exposure to microbially diverse materials and surroundings positively affects the human microbiome, immune system, and not least children's well-being, access to these places is unevenly distributed (Puhakka et al., 2019; Roslund, Parajuli et al., 2022; Roslund, Rantala et al., 2019). Economic inequality, and fiscal and social policy conditions affect parents' socioeconomic status and consequently children's lives by either compensating or reinforcing inequalities. The housing market sets the limits for the effect of socioeconomic status on what dwelling it is possible for parents to attain. Can parents afford a home with a garden? Or perhaps a city apartment with a lush green courtyard? Or a second home in the countryside? Moreover, local planning affects what green spaces are available in affluent and less affluent neighborhoods. Local job markets and infrastructure affect the possibilities of commuting, making rural and urban neighborhoods attractive. In many cities socioeconomically advantaged families tend to live in greener neighborhoods (e.g., Csomós et al., 2024; de Vries et al., 2020;

Buijs, & Snep 2020), and children of higher socioeconomic status are more likely to have a green home-school walk (Khanian et al., 2024).

The ecological diversity around the home may affect whether parents and children spend regularly extended time outside and what microbiota they will be exposed to. The frequency and period of exposure and differential diversity of microbial exposure may shape the proximal process via the gut-brain-axis. Research has yet to test these mechanisms, however, while not measuring green space, a recent cross-national study finds that access to ecologically rich outdoors space suitable for play increases children's wellbeing (Rubio-Cabañez, 2024). To sum up, socioeconomic status modulates access to green space and thereby potential exposure to natural microbiota affecting proximal processes hence potentially affecting child development due to socioeconomic differences. The link between the social and the biological raised here posits development as changing within synergistic relations.

Encounter 2: Parental Separation and Biosocial Entanglements

In research as well as in work with children experiencing parental separation, a key focus is to ensure the best interests of the child following the separation. A common conception is that the best interest of the child is closely linked to the child's relation with the parents as well as to the relationship between the parents. Children's views are often interpreted as an expression of the quality of these relationships. For this reason, the child-parent relationship and the parent-parent relationship are often foregrounded, omitting other relations, aspects, and spaces in the child's life (Warming & Alminde, 2025).

Children with separated parents often move, adjusting to everyday practices connected to, for instance, different homes that have different practices that create local microbial environments in those homes. These practices alter the composition and diversity of microbes related to the four ecological processes outlined above: dispersal, selection, diversification and drift. These practices include, inter alia, sanitation practices, presence of pets and plants, regularity of non-family members' visits, and routines of visiting microbially rich places, such as forests that can alter microbial diversity in the home. Change in environments means participating in different microbial communities, as different families, persons and places and their practices constitute specific microbial environments (see above). Because the child is composed of dynamic and constantly evolving ecological relations both within her body and externally, considering local microbial environments of homes and acknowledging children's microbiological constitution can lead to new ways of studying and understanding children's everyday lives, development and the proximal processes that synergistically shape them. Recent studies have suggested that the diversity of the microbial life in human surroundings can have an impact on children's physical wellbeing (e.g., Roslund et al., 2022). Children's wellbeing in different spaces/homes thus is connected to microbial diversity. Because humans are the primary bacterial vector in homes, mixing humans in new homes produces new bacterial communities in the new home (Lax et al., 2014). Subsequently, children's preferences following parental separation and what they perceive as pleasant spaces, which is often seen as connected to only human relations, might also need to be explored in connection to microbial environments manifesting in smells, tastes, plants and pets indicating ecological and microbial diversities (Mackerron & Mourato, 2013; Nisbet et al., 2009).

The microbial lens also expands what needs to be considered in children's views on separation, including the complex ecologies of parental separation. Considering children's sense of wellbeing based on microbial environments and their effect on proximal processes related to parental separation provides a fuller approximation and expands the relational considerations. In BEM, this kind of biosocial focus brings more attention to the importance of social practices as they shape microbial environments in interaction with the child-as-ecosystem. It is not only the child and her or his social relations, but a complexity of people's internal and external ecologies, ecologies of places and practices that could be also considered when studying and assessing children's experiences of parental separation. Besides, it is also important to understand how politics structuring this area promotes or limits microbial diversity of places, such as policies that promote equal parenting and children following the parents.

Encounter 3: Socialization in the More-than-Human World

BEM can be viewed as a theory of socialization due to its focus on child development within specific environmental contexts during which skills and abilities emerge from interaction between dispositions and the environment. In the bioecological model of Process-Person-Context-Time, Bronfenbrenner characterized the specific dynamics of socialization as synergistic proximal processes where each child has unique characteristics (Person) and unique socialization environments (Context) that together create unique proximal processes, which drive over time the socialization of the child. Prosocial behavior, as a part of socialization, is mediated both by the interpersonal relationships and certain dispositions of the child, such as empathy (Carrizales et al., 2023). The development of empathy is associated with warm and supportive caretaking relationships, and equal and trustworthy peer relationships (Boele et al., 2019).

For humans and other empathic animals, empathy can be considered a repertoire of proximate processes for moral and prosocial behavior (Preston & de Waal, 2002). Although empathy has traditionally been studied in the context of human intra-species relationships, growing attention is being directed toward inter-species empathy (e.g., Schnegg & Breyer, 2022) driven by findings that empathy is a predictor of pro-ecological attitudes and behavior in humans (e.g., Berenguer, 2007). Empathy provides knowledge of others through encountering them, while maintaining self-other distinction (Zahavi and Michael, 2018, p. 600). The 'other' refers to any entity that shares overlapping sensory (or other interaction) modalities, facilitating the transmission of social signals or affects across species or kingdom boundaries. This 'other' therefore is different to the Person or objects that Bronfenbrenner identifies as important in the Context (Bronfenbrenner & Morris, 2007). For instance, chemical signaling is employed in the communication between a human host and their associated microorganisms (Hughes & Sperandio, 2008). However, in the absence of social signals, empathic concern can also be elicited by imagination or acquired abstract knowledge of the other (Singer & Lamm, 2009) that Bronfenbrenner identified as signs. An example of human-microbes empathy is when a child alters their eating habits out of concern for the microbes residing in their gut. This empathic concern may have arisen either directly through signals received from microbes (stomach pain etc.), or through the child's imagination or acquired abstract knowledge of microbial wellbeing.

This multispecies perspective added to BEM alters our understanding of proximal processes, emphasizing the role of the body's multiple sensibilities, beyond experiences that come according to BEM with feelings and personal beliefs, in child participation within multispecies communities. The multispecies relations of the child lead to different kinds of proximal processes and hence socialization and recognizing those social capabilities that emerge beyond purely human communities (see more on eco-socialization theory as outlined by Keto and Forster (2021)). A multispecies understanding of the socialization process sheds light on those developmental and behavioral changes within the child that occur during reciprocal interactions with other organisms. Interaction with microbes begins in the womb (Aagaard et al., 2014) and continues throughout human development to the end of life, for us here, significantly influencing the child's development, physiology, psychology, cognition and behavior (Sarkar et al., 2018). A deeper understanding of these relationships, including the information exchanged within them, could also enable the child to act in a moral or prosocial manner, so to speak, toward their microbial partners.

Encounter 4: Microbial Life in Development, Health and Well-being

Environmental health research brings vital evidence for the need for mutual relations with multispecies communities in children's health, development and wellbeing. Today, most children in the world live in urban areas with possibilities for limited engagements with natural areas (United Nations Department of Economic and Social Affairs Population Division, 2019). Coincidently, an increasing number of children living in urban areas are also suffering from immune-mediated diseases, including asthma (Ege et al., 2012), type 1 diabetes (Kondrashova et al., 2005), atopy, and allergies (Hanski et al., 2012). According to the biodiversity hypothesis, the main reason for the increasing burden of immune-mediated diseases among urban children is the lack of contact with biodiverse ecologies and its microbes (Haahtela, 2019; Rook et al., 2003). Proximal processes can be considered as the priming of the developing immune system

in which commensal and pathogenic microbes and viruses of forests or lakes and oceans participate. A resilient immune system has the capacity to adapt to challenges, such as infection, diseases and more recently COVID-19, by developing and regulating an appropriate immune response (Haahtela et al., 2021).

There are several other proximal processes that we can give as examples. A child with few contacts with ecological microbiota more likely develops food allergies which may further affect her/his attitude towards food (Yu et al., 2024). The COVID-19 pandemic can be seen as a historical event which affected microbial compositions of bodies (perhaps even intergenerationally) and microbial relations in multiple ways, such as through extreme sanitization, limiting human contact and lack of exposure to microbes in natural spaces. Those children, who were born or were within their first three years of age are the most affected, since they might lack microbes (due to missing exposure and sanitized environments) that modulate developmental processes (Friedl et al., 2024)

Ecological relations thus are important for the development and maintenance of commensal microbiota, inhabiting the skin, gut and other mucosal surfaces, regulating children's metabolism, inflammation, neurodevelopment, mental health through gut-brain axis, and preventing pathogen growth and diseases (Rieder et al., 2017). Biodiversity intervention studies in Finland have demonstrated that modifying children's playground with microbiologically diverse surfaces enhances the immune regulation and health-associated commensal microbiota of urban children (e.g. Roslund et al., 2022). Daycare yards and other playgrounds enriched with diverse microbes may be a feasible approach for increasing well-being (Puhakka et al., 2019) and decreasing the prevalence of immune-mediated diseases among children. Biodiverse ecologies affect development and cognitive skills by shaping proximal processes between broader ecologies and microbes that are part of the Person (child-as-ecosystem) (Dadvand et al., 2015). These aspects and synergistic interactions between microbial communities and child-as-ecosystem affect the development of the child through proximal processes, however, they are not yet considered in BEM. Life processes are dependent on these mutual interactions thus require attention. Enhancing contact with diverse microbiota in local ecologies could be incorporated at any system level of BEM. For example, administrative authorities can promote changes in curricula or support building greener daycare yards. At the microsystem level, parents can incorporate the microbial world in everyday life through various practices, such as, exposing children more to green environments or composting and fermentation at home.

Conclusion

The four encounters staged above, first, open the child's ontological status to a new, more expanded and expansive multiplicity, that of the child-as-ecosystem. The understanding of the child-as-ecosystem foregrounds life processes at work which allow for a more complex consideration of proximal processes as well as *Person* and *Context*. In this way, the model can highlight how the ecological environment plays a part in the constitution of child bodies, development and orients attention to the importance in early childhood education to everyday practices that are microbial in nature, such as cleaning, feeding, educational and living places, nature visits and so on. Second, we demonstrated the importance of microbial environments and locally constituted child-as-ecosystems that are in flux. This gives further arguments for considering the biologies of *Person* and *Context*. His points to the importance of the provision of biodiverse and clean environment for optimal child development. Third, we argued that multispecies life processes need to be accounted for in BEM and gave examples of possible ways to do so. Microbial co-existence helps to resist ideas of linear development by highlighting the continuous reconstitution of all bodies, young and old, through the interdependencies between microbes and the physiological processes within human bodies and the nested ecologies in which bodies are situated. This insight calls for a reconsideration of notions of childhood in early childhood education, highlighting the importance to understand child bodies as highly permeable for environmental influences and interdependent with environmental processes.

BEM carefully analyses the social field and focuses on synergistic proximal processes that drive development; however, with the advancements in contemporary host-microbiome science, we have argued, BEM would be enhanced with considering biological processes that constitute children's

development and wellbeing. Through the encounters above, we have described ways in which biological processes that are different from disposition, resources and experience defined in BEM have been shown to play a part in children's development and wellbeing. In doing so, we have identified reasons to think that BEM can become more 'bioecological' than it presently is and hence can grow in its ability to model children's lives and thus may, in time, expand its range of policy and practice applications. In our hope, this would be to consider in policy anthropogenic changes to the environment which reconstitute children's bodies by altering their physiology, for example, microplastics in daycare air or agricultural pesticides, antibiotics and growth hormones in children's food. Policy regarding early childhood thus must consider pollution, biodiversity loss and nature exposure, hygiene and cleaning practices, and processed food, all altering children's microbiome and for creating microbially rich environments for children.

We have also noted that that the developing *Person* must be considered as an ecosystem living within nested ecologies, which are broader ecologies of multispecies relations (more-than human world). In other words, any *Person* needs to be seen as an open-ended multispecies community nested in and shaped by bioecologies, where ecologies beyond humans also include biodiverse ecologies. The development and wellbeing of any given *Person* is best understood as intra-actions across multispecies communities which are affected by wide-ranging ecological conditions. The present-day context of biodiversity loss requires us to see ourselves also in terms of and part of ecosystems. Thus, inequalities in human and more-than-human flourishing need to be understood in terms of bioecological interdependencies and synergies. This change might require the rethinking of the foundations of Bronfenbrenners' bioecological model.

Throughout his career, Bronfenbrenner worked to expand and fine tune BEM by informing it with experimental research or new research on development, such as human genetic expression (Rosa & Tudge, 2013). We have followed this path to review what opportunities and challenges can emerge when BEM is placed in dialogue with host-microbiome research. BEM made significant contributions to policy and practice over the years, and we are committed to continuing this work as part of a wider interdisciplinary project that seeks to make sense of childhoods and child development in the light of developing knowledge of microbial life and biodiversity loss (Microbial Childhood Collaboratory).

Declarations

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