

A child-centric microbiology education framework

Where does my microbiome come from?  
Early environments matter:  
microbiome acquisition and influence on health

*When do I start to have microbes on my body and how do I get them?*



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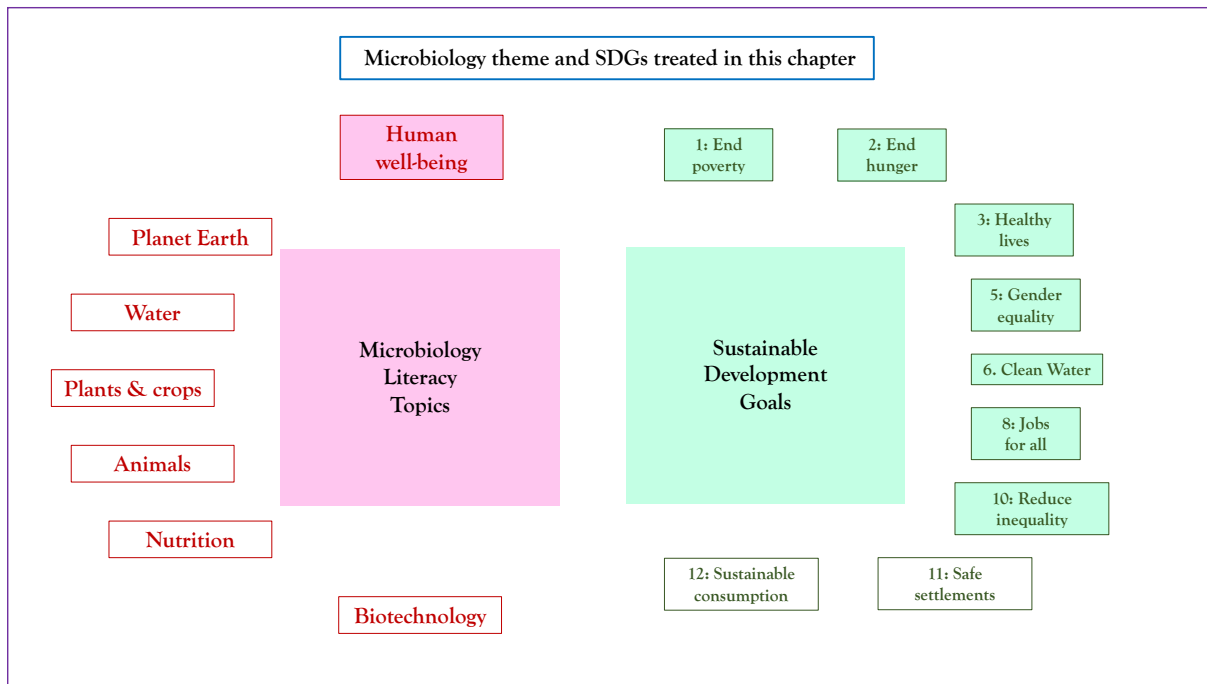
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## Early Environments Matter

### Storyline

The community of microbes living in and on the human body, known as the human microbiota, is shaped by contact with the environment. As a result, its composition varies between individuals who live in different parts of the world and practice different lifestyles. The microbiota first starts to develop when infants are born and are exposed to microbes from their mothers' bodies during delivery. Immediately following birth, infants continue to acquire microbes from different sources in their surrounding environment, including animals and other people. Since individuals can share microbes when they come into contact with each other, infants can receive microbes from the people who take care of them, such as parents, siblings, grandparents, and nannies. At the same time that infants are developing their own microbiota, their immune systems are also developing. Since exposure to microbes in early life helps train the immune system, the infant microbiome likely affects how the immune system develops and functions. It may also affect how metabolism and behavior are programmed. Within this framework, the relationship between early life environments, microbial exposures, and the immune system likely affects infant short and long-term health outcomes. Therefore, understanding how infants develop their own microbiota can connect the health of environments, families, and infants. Promoting the development of a healthy microbiota by supporting specific birth and infant care practices, as well as ensuring families can occupy environments with beneficial microbes, is related to multiple sustainable development goals.

### Microbiology and Societal Context



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*The microbiology:* microbial sharing; microbial colonization; ecological processes of the developing infant microbiota; the microbiota of breast milk; effect of antibiotics. *Societal Context:* integrating the microbiota into birth and infant care practices, family-centered health policy. *Sustainability Issues:* access to healthcare; health and well-being; supporting mothers.

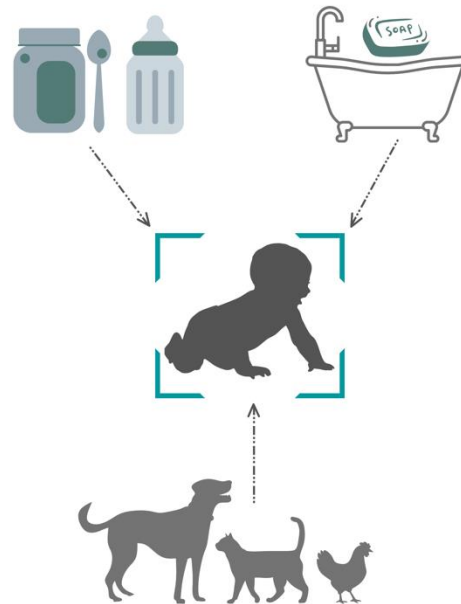
### Early Environments Matter: The Microbiology

1. *Where do microbes live in and on the body?* Microbes inhabit all parts of the body. They can be found on the skin, in the nose, mouth, lungs, in the small and large intestines, and in the reproductive tract. There is even evidence that some areas of the body that were long believed to be sterile, such as the urinary tract and the blood, may contain small amounts of microbes. The number and types of microbes that live in each of these body sites differs as a result of factors such as moisture, pH, and exposure to the environment. Microbes can also be transferred between body sites of the same person, between two people, or between a person and the environment. However, which microbes can survive in which body site depends on the traits of a given body site.

2. *When do microbes appear in and on the body?* Adults have microbial communities associated with most parts of their body, but these communities start to develop during infancy and early childhood. Newborns receive their first major exposure to microbes at birth as they come into contact with microbes associated with their mothers' bodies (e.g. the vaginal tract). They are also exposed to microbes in their birth environment, whether that be the home, a hospital, or another setting. Whether a birth is vaginal or via Caesarian-section can influence the types of microbes to which an infant is exposed. Infants born vaginally are exposed more to maternal microbes while infants born via Cesarean-section are exposed more to environmental microbes.

After birth, newborns continue to be exposed to microbes through contact with their physical and social environment. Practices like skin-to-skin contact transfer microbes to infants, and breast milk contains both live microbes and compounds that microbes can use as food. Behaviors such as crawling on the floor, putting things in the mouth, and playing with pets or siblings can also expose babies to microbes. Bathing and cleaning practices, as well as when and how babies are introduced to solid foods, also affect their developing microbial communities.

Because of these exposures, the microbiota becomes more complex over time - with the number and types of microbes at each body site changing rapidly from month to month. Also, the microbiota of different body sites are very similar to one another at birth and become more distinct from each other over time as a result of these processes.

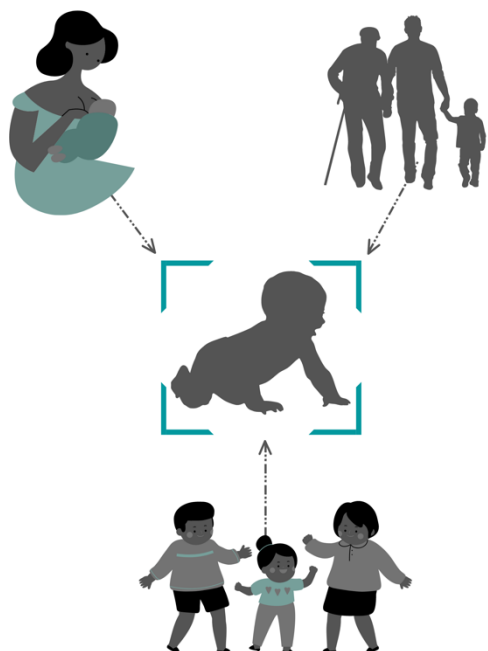


In addition to contact with people, the infant microbiome is affected by diet, bathing, and exposure to animals.

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The microbiota is generally considered to stabilize and look adult-like at three years of age. However, this evidence comes mostly from research on the gut microbiota. More research needs to be done on the microbiota of other body sites, as well as during later stages of childhood, in order to fully understand the development of the body's microbial communities over time.

3. *How do social environments affect the development of the microbiome?* When people come into contact with each other, they are able to spread microbes to each other's bodies. This microbial sharing can occur when people shake hands or hug each other. During birth, newborns receive their first transfer of microbes from their mothers' bodies. It is thought that infants



Early life social environments impact the developing infant microbiota.

continue to receive microbes when they come into contact with other people, including parents and siblings. When people hold, feed, and play with infants, they can spread their own microbes to the infant body. As one example, infants who are breastfed will continue to receive microbes from their mothers' breast milk, which contains live microbes that can live in the gut of infants. Infants are also exposed to microbes in formula and solid foods, as well as the microbes that live on the bodies of the people who feed them. Since infants require different types of care as they grow older, there are likely to be differences in how microbes are shared between infants and their caregivers over time. Further, infant caregiving practices vary across populations, suggesting that infants living in different parts of the world are not always exposed to the same kinds of microbes. However, scientists don't yet fully understand how the infant microbiome varies across different family structures or cultures.

4. *How do physical environments affect the development of the microbiome?* Just like people can share microbes when they come into contact with each other, we can also pick up microbes from different components of our environments. As one example, microbes live inside people's houses, but the types of microbes present can depend on the materials used to build the house, as well as the kinds of products that are used to clean the house. This means that even within one neighborhood, infants may be exposed to different types of microbes simply because they live in different houses.

In addition to the microbes living inside houses, there are many microbes living in nature, including in the soil and on plants and animals. Studies show that coming into contact with soil and leaves can transfer microbes directly to our skin, and that people and their pets tend to have similar microbes on their bodies. This suggests that infants who live in different towns, cities, and countries may not be exposed to the same types of microbes, just as infants who spend more time outdoors are likely to interact with different microbes compared to infants who spend more time indoors. Additionally, hygiene practices, including bathing infants with different kinds of water and soap, can contribute to variation in the infant microbiome.

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When thinking about infants' exposure to environmental microbes, it is also important to consider how behaviors and practices can change as infants grow older and become more mobile. For example, older infants who are crawling or learning to walk can explore their environments to a greater degree than infants who are too young to move independently. Infants may therefore interact with different types of microbes as they grow older and are able to explore the world around them.

5. *How do these factors vary across different environments?* Across the world, infants live in many types of family structures, houses, neighborhoods, and cultures, which results in being exposed to different types of microbes. Since people's cultures have a strong influence on their diet and contact with other people and animals, we can expect to see differences in infants' microbial exposures across cultures and populations. For example, infant diets are different in different parts of the world. There is variation in the length and degree of breastfeeding, which influences infant exposure to maternal microbes both in breastmilk and on maternal skin. Different foods are also used for weaning depending on cultural traditions, and these foods can impact the types of microbes that are introduced into the infant gut as well as what microbes can survive in the infant gut.

Beyond diet, infant social structures vary globally. It is common for infants in certain cultures to be raised in households with family members from different generations, sometimes including parents, aunts and uncles, and grandparents. Infants in these larger households likely come into contact with more people, and therefore could be exposed to a larger pool of microbes. At the same time, parents who work outside of the home and do not live with extended family members often rely on non-relatives to help care for their infants. In this scenario, infants may be exposed to new types of microbes at daycare centers, as well as from the bodies of nannies or other caregivers.

Across populations, there are also considerable differences in people's access to water and different kinds of hygiene products, like soaps and lotions. In some settings, infants are bathed in water that has been treated to remove microbes, and may also be bathed with soaps that are designed to remove microbes from infants' skin. On the other hand, some infants are bathed in untreated water which may contain microbes that can establish in and on the infant body. Sometimes, the microbes in water can make infants sick, but scientists don't know as much about how beneficial microbes in water can contribute to healthy infant microbiomes. Finally, keeping pets in the home is a practice that varies widely across cultures and populations. Since pets can contribute to the indoor microbial environment, infants who live in households with pets may be exposed to different types of microbes than infants who live in households without pets.

6. *What is the impact of the microbiota on health?* Many studies have linked early life environments to health outcomes later in life. There are many biological pathways through which these impacts could operate, but research increasingly suggests that environmental effects on the developing microbiota are important. The gut and skin microbiota train the immune system in early life and help regulate responses to infection in later life. Microbial metabolites help tell different parts of the immune system when to react. The gut microbiome can also metabolize hormones and neurotransmitters and appears to influence the stress response. Finally, the gut microbiota produces molecules such as short-chain fatty acids that influence nutrition and affect

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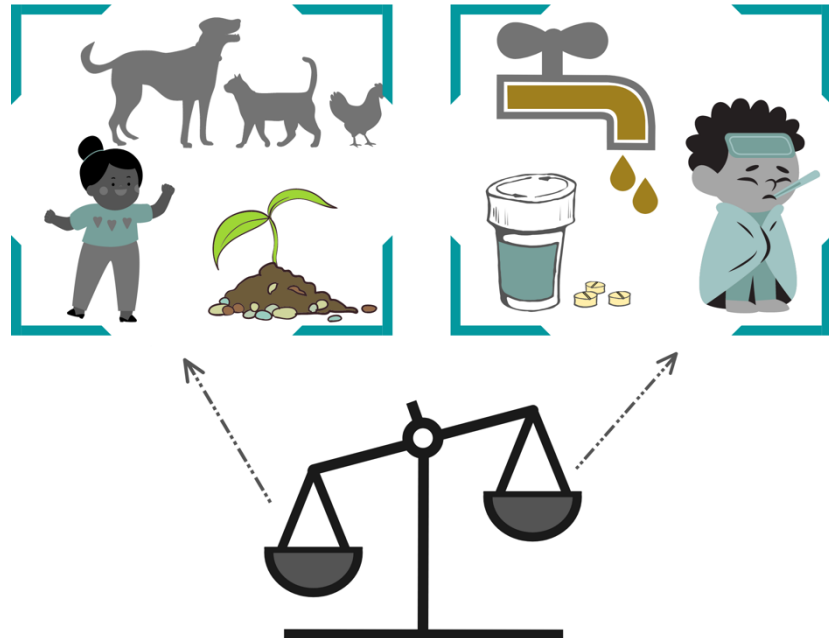
how host metabolism works, among other things. Therefore, if early life environments alter the types of microbes in the body, it can have widespread health consequences.

Studies are still being done to determine exactly what types of microbiota are healthier. In adulthood, more diverse microbiota are believed to be more resistant to invasion by pathogens and provide more potentially beneficial services to hosts. But during infancy, lower microbial diversity is thought to be a good sign of microbial community development in certain contexts. This difference may be because certain types of microbes are necessary for programming body systems early in life, and high microbial diversity is a sign that other types of non-beneficial microbes have entered the body. An active area of research is identifying which groups of microbial taxa and/or functions may act as 'keystone' taxa or genes that are disproportionately influential in shaping overall community function and host health.

7. *What can we do to promote diverse microbial exposures for infants?* While researchers are still trying to understand exactly which microbes affect which aspects of health and how they

are acquired, there are some behaviors that seem beneficial for promoting the development of a healthy microbiota during early life. Overall, the goal is to help infants and children avoid infection from pathogenic microbes while also trying to ensure they are exposed to potentially good microbes. To achieve this balance, families should have access to clean water and be able to wash children or houses when there is contact with a potential source of infection. However,

families should also avoid over-cleaning and allow infants and children to play outside in the dirt where they are exposed to a range of potentially beneficial environmental microbes. Increased social contact with healthy family members, friends, and other caregivers will also facilitate microbial transfer. Having healthy animals such as pets around the house also appears to support the development of a healthy microbiota. Finally, while antibiotics are an essential tool for fighting infection, families should avoid overuse, particularly for health conditions that antibiotics cannot treat, such as the common cold. Because antibiotics kill beneficial microbes in and on the body in addition to infectious microbes, overuse of antibiotics can have a big impact on the development of the microbiota.



Ensuring the healthy development of the microbiota requires balancing the avoidance of pathogenic microbes and antibiotics with the exposure to sources of beneficial

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### Relevance for Sustainable Development Goals and Grand Challenges

- **Goal 1. End poverty.** Families need financial resources to be able to create healthy infant environments. Having food security, reliable child care, and protected family leave time can all contribute to positive birth and infant care practices that promote the development of the microbiota and, ultimately, health.
- **Goal 2. End Hunger.** Families without reliable access to food will not be able to spend extra time, energy, and resources worrying about other aspects of infant environments that could have important health effects. Further, without sufficient nutrition, educational resources, and support, mothers may not be able to breastfeed successfully. Breastmilk is a critical part of infant microbial development, not to mention other aspects of health.
- **Goal 3. Healthy lives.** Since the immune system requires signals from microbes for proper development, exposure to a diverse suite of microbes in early life is likely to contribute to a well-functioning immune system. This has implications for both short and long-term health outcomes.
- **Goal 5. Gender equality.** Mothers need to be able to control their bodies and environments as well as those of their infants to promote healthy microbial exposures in early life and positively impact health. Without financial resources, the ability to make decisions, and access to information, the ability of mothers to promote infant health is limited.
- **Goal 6. - Clean water and sanitation.** Access to clean water for bathing and drinking is an important component of reducing infants' exposure to microbes that can make them sick. However, more research is needed to understand how beneficial microbes found in water can contribute to a healthy infant microbiome, as well as how using different types of soap can help or harm the developing skin microbiome.
- **Goal 8. Decent Work and Economic Development.** Families need financial resources and supportive employers to be able to create healthy infant environments. Good salaries will provide money for food, housing, and childcare, all of which are key parts of microbial development. However, policies are also necessary that allow for family leave during and after birth as well as personal days to improve family flexibility in response to illness or other challenges.
- **Goal 10. Reduced Inequalities.** Inequalities are often experienced through people's environments. Groups that experience marginalization or discrimination often cannot choose the types of environmental microbial exposures their children will have, and limited access to health care, financial resources, and support can limit decisions around birth and childcare. Reducing inequality can therefore improve families' ability to influence infant microbial development and health.

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## Potential Considerations for Decisions

### *1. Individual*

- a. Birth mode and environment
- b. Skin-to-skin contact and breastfeeding
- c. Infant care networks
- d. Outdoor activities
- e. Diet choices
- f. Antibiotic use
- g. Cleaning practices
- h. Handwashing and bathing

### *2. Community policies*

- a. Safe homes, neighborhoods, and community spaces for kids to spend time outdoors
- b. Community spaces where people and pets can gather
- c. Community spaces for moms
- d. Clean water
- e. Health provider information for new families

### *3. National policies*

- a. Parental leave policies
- b. Infrastructure (and cultural shift) to support breastfeeding/pumping at work and in public spaces
- c. Pediatric/medical guidelines (e.g. bathing and feeding recommendations)
- d. Family education

## Pupil Participation

### *1. Class discussion of policies surrounding birth and family leave.*

### *2. Pupil stakeholder awareness*

- a. Maintaining a healthy microbiome has several positive contributions to SDGs. Which of these are most important to you personally/as a class?
- b. How could local culture surrounding birth and childcare affect the microbiota?
- c. Who should make decisions for babies? Solely families, doctors?

### *4. Exercises*

- a. Brainstorm early life practices that are likely to have positive versus negative effects on the microbiota.
- b. How do you predict that different family structures shape how microbes are shared to infants? (e.g. intergenerational families, sibs vs no sibs, etc.)
- c. There are many ways early life environments can affect health. How might you go about determining the extent to which microbes are playing a role?



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d. The COVID-19 pandemic altered how some families participate in birth and childcare. How might you test which changes have had a bigger impact on microbial development?

### The Evidence Base – Teaching Aids and Further Reading

#### *Educational Videos*

<https://www.gutmicrobiotaforhealth.com/interview-jose-clemente-early-life-changes-microbiota-result-c-section-may-responsible-diseases-children-later/>

<https://www.youtube.com/watch?v=hxFjxBy555Q>

<https://letthemeatdirt.com/>

<https://www.biointeractive.org/planning-tools/science-news/baby-its-dirty-outside-nurturing-infant-microbiome>

[https://www.ted.com/talks/henna\\_maria\\_uusitupa\\_how\\_the\\_gut\\_microbes\\_you\\_re\\_born\\_with\\_affect\\_our\\_lifelong\\_health/transcript?language=en](https://www.ted.com/talks/henna_maria_uusitupa_how_the_gut_microbes_you_re_born_with_affect_our_lifelong_health/transcript?language=en)

#### *Articles*

<https://www.nationalgeographic.com/science/article/how-breast-milk-engineers-a-babys-gut-and-gut-microbes>

<https://theconversation.com/early-exposure-to-infections-doesnt-protect-against-allergies-but-getting-into-nature-might-126603>

<https://www.theguardian.com/news/2018/mar/26/the-human-microbiome-why-our-microbes-could-be-key-to-our-health>

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