The Microbes in our Home

Hey Sis: today we learned that microbes are everywhere – is that a bad thing?

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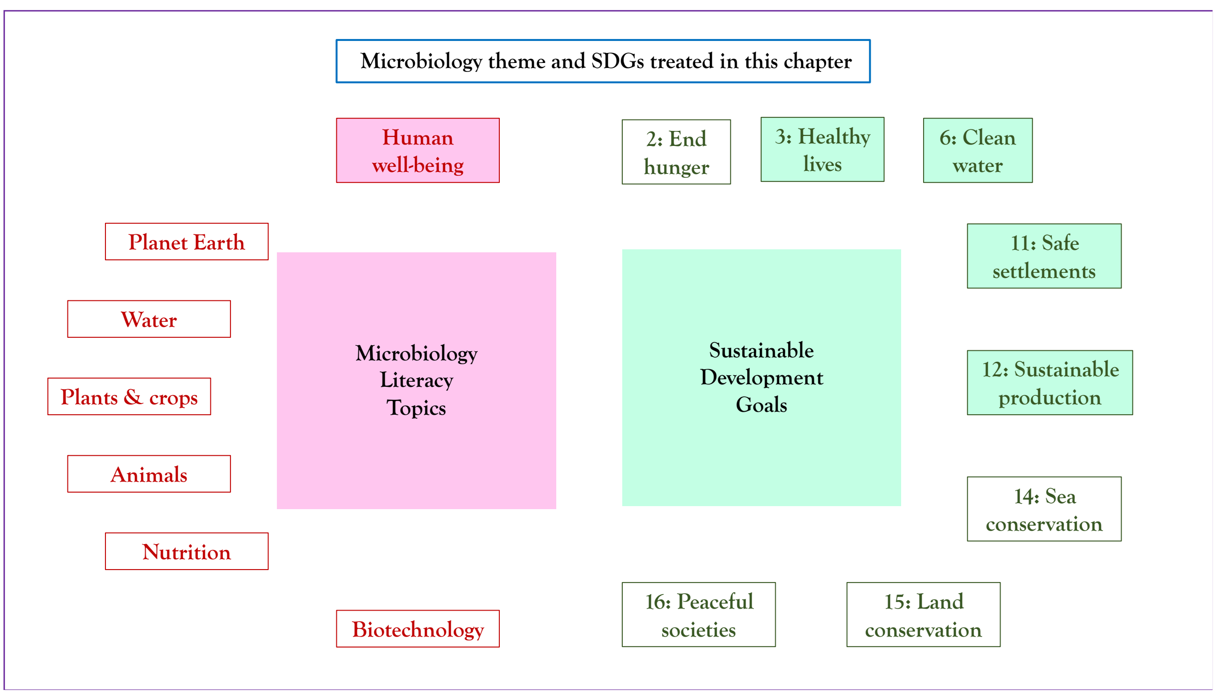
Storyline

Whether we are aware of it or not, our homes are inhabited by a wide variety of microorganisms. Although our homes are designed with our comfort in mind, they also contain a variety of environments for microbes. Some of those environments are highly inhospitable, like dry, barren surfaces, while others are chronically flooded and rich in nutrients, like sink drains. Because we spend 90% of our time indoors, much of which is spent in our homes, understanding these microbes is critical to successful cohabitation. Homes are an important venue for microbial exposure, potentially helping build healthy immune systems in children or exacerbating allergies and asthma in adolescents and adults. Understanding our microbial cohabitants, how they experience our shared home environment, and how we can best manage them will ultimately lead to better building design and operation.

The Microbiology and Societal Context

The microbiology: microbiota of the built environment; microbiomes and diversity maintenance; air microbiota and ventilation; immune system development; home cleaning and antimicrobials; microbial volatile organic compounds; pathogens. *Sustainability issues*: health; clean water; safe settlements; sustainable production and consumption.



The microbes in our home: the Microbiology

1. ***Most microbes in our homes are harmless, but some can be problematic.*** Microbial diversity is immense, with estimates of the number of microbial species ranging from millions to trillions. The ones we are most familiar with are the pathogens, a few special organisms that commonly cause disease. However, there are only about 1400 species of pathogens (including multicellular parasites). The number of microbial species that are pathogenic is somewhere between a few percent and one in a billion. Of the remaining species, some are invaluable: the microflora within the human intestine provides nourishment, regulates epithelial development, and is critical to immune system functioning. The microflora in our intestines, airways, and on our skin help defend us from pathogens. The microbes in and on the human body weighs three pounds, nearly as much as our brains.

Various environmental conditions select for different microorganisms. Outside of the human body, microorganisms have been found in incredibly diverse environments, including high-pressure deep-sea vents and near-freezing pools of glacial ice melt. Many of these organisms are obligate extremophiles, meaning they would not be able to survive in the human body or the moderate temperature environments that we prefer. However, some of these extreme environmental conditions are present within our homes. Thus, even in extreme environments that do not seem hospitable to life, microbes are capable of adapting and thriving.

2. ***Microbes in the home come from humans and outdoor environments.*** Occupants, including humans and their pets, both shed and collect microbes from the environments they inhabit. The built environment is colonized by its occupants' microbiota, which is subsequently selected for by unique environmental factors. In turn, an individual's microbiome carries traces of microbiota from each environment they visit. Thus, the microbiomes of the built environment and its occupants share a reciprocal relationship: we share our microbes with our homes; they share theirs with us!

Exposure to a diverse microbial community is essential to maintaining a healthy immune system. Without diversity, the immune system grows reactive to harmless, though now uncommon, stimuli (e.g., allergies). Dogs can also help to increase the diversity and richness of the indoor environment. These furry companions carry microbes from the outdoors into the homes they occupy, thus increasing the abundance of microbes that are not associated with humans. Ventilation likewise alters the structure of the indoor environment. While closed ventilation systems circulate indoor air, open systems allow outdoor air into the home. Therefore, microbes associated with outdoor air can be carried indoors, further increasing the diversity and richness of the home environment. Interestingly, geography and outdoor conditions have a smaller impact than occupancy when it comes to bacteria – but not fungi.

3. ***Your home harbors a wide variety of wildly different habitats.*** Bacterial communities inside homes are more diverse than the outdoors, as they include both microbes found outside of homes as well as the microbes that are restricted to the inside of homes or originate from indoor sources. One of the biggest drivers of the types of microorganisms found on surfaces in a specific environment within a home is how humans interact with them. Commonly touched surfaces, like door handles and light switches, often harbor microorganisms associated with

human skin. We also find a mix of human-associated bacteria, as well as environmental organisms, in dust. The exact mix can change based on a myriad of reasons: the activities of the people inside the home, what gender they are, how many and what kinds of pets are present, the design of the building, even water damage. However, these environments are dry and devoid of nutrients, so it is widely expected that most of these organisms are dead or dying.

In contrast, there are many environments that are replete with water and nutrients. For example, kitchen sponges can trap water and food, providing a suitable habitat for many organisms, including potentially problematic foodborne pathogens like *Campylobacter* and *Salmonella*. Although they endure high temperature water, detergents, and high pressures, dishwashers also host bacteria – as well as some fungi. Toothbrushes are also exposed to food and water, but we also interact with them more directly than with kitchen sponges. As a result, the microbes that dominate toothbrushes are more than likely from your mouth and skin.

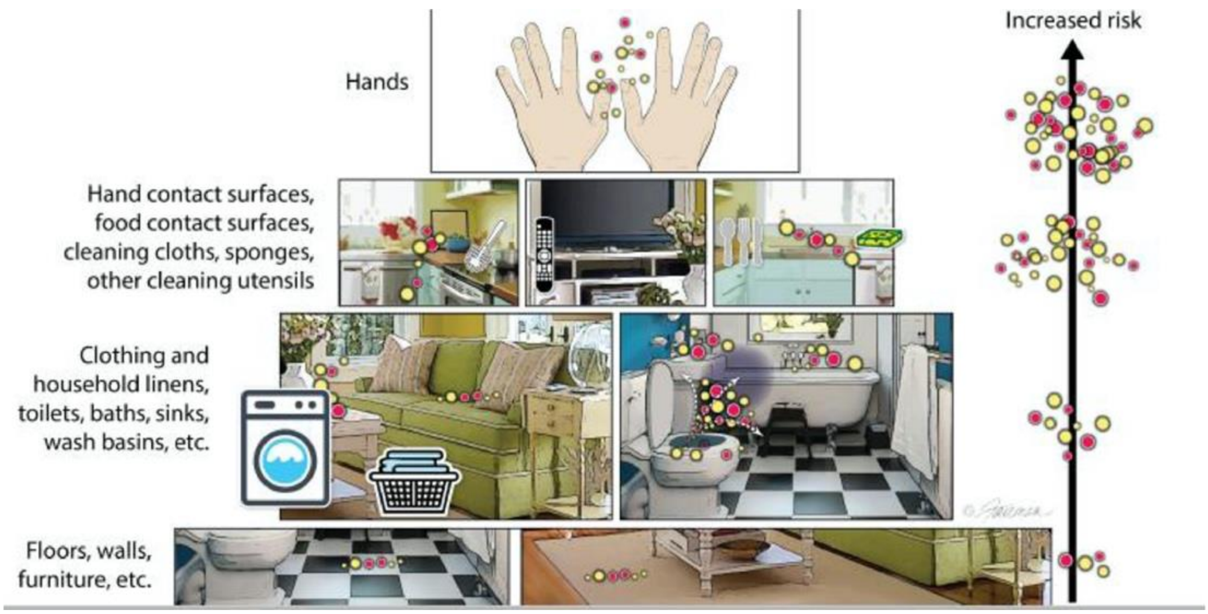


Figure 1. Places in our home where we can find microbes (Scott et al., 2020).
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4. ***Microbes in homes can be alive, dead, or somewhere in between.*** Recent advances in technology have led to an explosion of "microbiome" studies, revealing vast amounts of previously undetected microbial diversity. However, methods based solely on detection of DNA do not conclusively demonstrate the presence of viable microbes – those that are alive. Some have hypothesized that your home is full of "desert-like environments where microbes passively accumulate" and are mostly dead. This may be true of indoor dust, but nevertheless early studies reveal lots of culturable microbes. Even if 99.999% of microbial cells are dead, if you start with millions or billions, you still have tens to thousands alive!

In addition, different niches may have vastly different amounts of viability and activity. Wet areas, like premise plumbing and kitchen sponges, likely have the water and nutrients needed to support life. These places may have unique stressors that influence which microbes survive and which functions they perform. Furthermore, viability may not be strictly necessary for human health, as nonviable microbes can still be sources of toxins, allergens, and mobile antibiotic resistance genes. Understanding viability and function will help understand whether indoor microbiomes are true microbial communities with ecological functions or passive collection sites for detritus.

5. ***Microbes that are alive and active "exhale" microbial volatile organic chemicals.*** Many things in our home, from our sofas to our dining tables, are constantly emitting different chemicals. Some are harmless, but certain groups such as volatile organic compounds (VOCs) are a concern because they can have unpleasant odors and even cause health issues.

VOCs are not only created by our paint and furniture, but also from the microorganisms around us, which can either transform VOCs or make their own microbial volatile organic compounds (mVOCs). Although some mVOCs can be detected by our noses, most need sensitive instruments to measure. Understanding whether mVOCs are present is important because they are often an indicator of issues such as dampness and/or growth of molds, which produce spores that we know can be bad for our health.

Most mVOC measurements have been done by letting mVOCs accumulate and measuring them later, but this makes it difficult to understand which microbes are making what mVOCs. Furthermore, only viable, active microbes produce mVOCs, and the specific combination of active microbes in an ecosystem produces different mVOCs. Future work needs to use real-time monitoring of chemical emissions, coupled with microbial detection methods that distinguish between live and dead cells. This approach will give us a better understanding of the relationship between specific microorganisms and mVOCs when interacting with both each other and the VOCs already present in our homes.

6. ***Approaches to removing microbes (i.e., cleaning) range from antimicrobial to probiotic.*** Although humans have always had a desire to keep their homes clean, the idea transformed to the need to sterilize our homes, after the discovery of microorganisms. Many household cleaning products are antimicrobial that use chemicals to kill or inhibit microorganisms by preventing them from surviving. Antimicrobial chemicals target different parts of the cell, including the cell wall and critical functions like DNA replication. However, bacteria are able to evolve and become resistant to antimicrobials and cause even more problems to human health. Antimicrobials from cleaning products can even end up in the environment when we wash them out of our homes via sinks and showers. The rise of resistance is causing us to reexamine how we clean, especially when the majority of microorganism in our homes are harmless and may even be beneficial. Physical methods like wiping a sponge across your kitchen counter, or even changing the surface of the counter itself to prevent bacteria attaching, may be sufficient and preferable to chemical cleaning.

7. ***Antimicrobial resistance: a global health challenge in your home.*** With the growing concern for antimicrobial resistance, it is critical to understand that this threat can be mitigated with the appropriate actions. Simple, preventative steps can take place directly in the home. Cleaning products sold with antimicrobial agents are often unnecessary. They are commonly marketed as a superior alternative to traditional products when in fact simply washing with soap and water is often sufficiently effective to reduce transmission of pathogens.

Limited resource availability in the natural environment drives competition among organisms. Notably, bacteria such as soil-associated actinomycetes, synthesize molecules that disrupt the growth and function of their bacterial competitors. These molecules are called antibiotics. After their discovery in the early twentieth century, commercial production of antibiotics revolutionized modern medicine by providing a cure for previously untreatable infectious diseases. Unfortunately, the golden age of antibiotics did not last long. Frequent misuse of antibiotics in commercial and medical sectors has selected for bacteria with diminished susceptibility to antibiotics. A growing number of patients with bacterial infections failed to respond to therapeutic doses and antibiotic resistant strains of pathogenic species were soon cultured from patient-derived samples. However, the origins of antibiotic resistance mechanisms largely do not reside in anthropogenic stressors; rather, they are the results of an evolutionary arms race between antibiotic-producing organisms. Many of the genetic mechanisms underlying antibiotics resistance originate in the natural environment.

A diverse microbiome is critical for our health and prevents pathogens from colonizing available niches whereas antimicrobial-containing cleaners can substantially reduce diversity. By limiting one's use of antibiotics, one reduces the selective pressure for antibiotic resistance genes to accumulate.

Relevance for Sustainable Development Goals and Grand Challenges

The United Nations has developed *Sustainable Development Goals*: https://sdgs.un.org/goals
Four goals are especially relevant to the microbes in our home:

- **Goal 3. Ensure healthy lives and promote well-being for all at all ages** (improve health, reduce preventable disease and premature deaths). Pathogens. Antimicrobial resistance. MVOCs

- **Goal 6. Ensure availability and sustainable management of water and sanitation for** all (assure safe drinking water, improve water quality, reduce pollution, protect water-related ecosystems). Clean water and sanitation. Showers and plumbing.

- **Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable** Sustainable cities and communities. Stop the spread of antimicrobial resistance and infectious disease.

- **Goal 12. Ensure sustainable consumption and production patterns** (achieve sustainable production and use/consumption practices, reduce waste production/pollutant release into the environment, inform people about sustainable development practices). Consider the products we use in our homes. Practice responsible production and consumption.

Potential Implications for Decisions

1. ***Individual***
    a. Deciding what type of cleaning products to use in home
    b. Deciding how to operate ventilation (e.g., opening windows or using an air cleaner)
2. ***Community policies***
    a. Builders and developers can consider how the materials they use will impact microbial growth and dampness
3. ***National policies***
    a. Banning chemicals known to cause antimicrobial resistance from consumer cleaning products
    b. Amending building codes, especially for ventilation
    c. Designing drinking water treatment standards to account for microbes in premise plumbing

The Evidence Base, Further Reading and Teaching Aids

The Great Indoors: The Surprising Science of How Buildings Shape Our Behavior, Health, and Happiness by Emily Anthes
https://us.macmillan.com/books/9780374716684

Community of Microbes
https://www.communityofmicrobes.com/house
https://www.communityofmicrobes.com/shower

Never Home Alone: From Microbes to Millipedes, Camel Crickets, and Honeybees, the Natural History of Where We Live by Rob Dunn
http://robdunnlab.com/science-portfolio/never-home-alone/?portfolioCats=12

The US EPA website on the Indoor Microbiome
https://www.epa.gov/indoor-air-quality-iaq/indoor-microbiome

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Glossary

Antibiotic: compounds that target bacteria to treat and prevent infection
Anthropogenic: caused or influenced by people
Antimicrobial: something that kills or stops the growth of microorganisms
Antimicrobial resistance: when a microorganism cannot be harmed by antimicrobials
Bacteria: Single-celled living microorganisms with cell walls, but lack a distinct nucleus
Built Environment: the person-made environment comprised of structures that provide people with living, working, and recreational space
Cell wall: the outer coating of some types of cells
Campylobacter: a kind of bacteria that is linked to foodborne illness which is usually spread by ingestion of contaminated food (i.e.; raw or undercooked poultry), contaminated water, raw milk, or handling infected animal feces
Cohabitation: living things, or cohabitants, that exist in the same space at the same time

Culturable: microorganisms that can be grown in laboratory conditions
DNA: DNA stands for deoxyribonucleic acid, it is small material inside all living things that carries information about how it will look and function
DNA replication: the process where DNA creates a copy of itself
Ecosystem: the combination of both a community of organisms and the environment where they interact
Epithelial: the tissue that covers all organs of the body, what the deep layer of skin is comprised of, it protects the body and serves as a barrier
Fungi: microorganisms which include mushrooms, yeasts, and mold
Immune System: one of the body's systems made up of organs, cells, and proteins which protects it from illness
Microbe: see microorganism
Microbial volatile organic compound (mVOC): VOCs produced by microorganisms
Microbiome: a community of microorganisms within a body, part of the body, or environment
Microflora: The collection of microorganisms that live on or inside
Microorganism or Microbe: microscopic organisms such as bacteria, fungi and viruses
Niche: a space with varying resources and environmental conditions that together create conditions where bacteria can grow and survive
Nutrient: chemicals that are either from the environment (essential) or generated internally (non-essential) that are used for growth and metabolism of a microorganism
Parasite: an organism that survives on or in another organism at the other organism's expense, often causing harm to it
Pathogen: a disease-causing organism
Probiotic: live microorganisms or "good bacteria" found in fermented foods, cultured milk, yogurt, or medication which can improve gut health
Salmonella: a group of bacteria that is linked to illness which can spread by handling reptiles or ingestion of raw poultry, eggs, beef, and sometimes on unwashed fruit and vegetables
Viable but non-culturable (VBNC): microorganisms that are living, but cannot be grown outside of their natural environment