Life in a Bubble?
We need our microbes!

What are microbes, where do they live, and how do they help us thrive?

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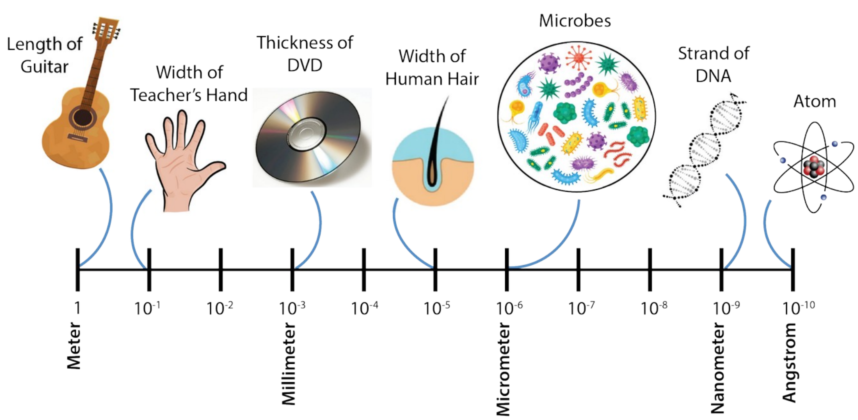
Storyline

Our world is dominated by microbes, single celled organisms that are invisible to the human eye. In fact, microorganisms occupy every known space and surface on the planet, including within ourselves. Such a fact may be disconcerting to many. Preconceived notions have us believing that all microbes are dangerous to our health (microbes = germs?). With such a notion in mind we are often encouraged to constantly sanitize, sterilize, and disinfect and create a microbe-free "bubble" to protect ourselves and our loved ones from harm. However, microbes actually play a crucial role in maintaining our physical and mental health. Within our bodies we each carry a complex and distinct community of diverse microbial species, which must be managed to ensure the proper functioning of our immune systems. Microbes also serve as nature's invisible balancing force, ensuring the continuation of various natural processes required for sustaining life on Earth. We explore some of the unexpected ways in which small but mighty microbes help us live healthier and happier lives, and conclude with the emphasis that we must aim to understand and manage the vast communities of microbes that reside all around us and inside our bodies.

We need our microbes!

Introduction

1. When you hear the word "microbe", what typically comes to mind? Microbes are single celled organisms that encompass every domain of life. The term encompasses bacteria, archaea, eukaryotes, and even non-living viruses. While microbes are typically too small for us to see (the smallest objects visible to the naked eye are ~100µm), they are quite literally found everywhere on the planet.



They are found in soils and oceans, surfaces and the air. Scientists have even found live microorganisms in ancient fossils! Microbial life on Earth is incredibly diverse with an estimated existence of many trillions of different species, most of which have yet to be identified. They are also found on us and inside our bodies in our microbiome. In fact, recent studies have discovered that, within the average person, there are as many microbial cells as human cells. This means that you, as a person, are not just a person. You are actually an entire ecosystem housing a micro-planet of invisibly small residents - you contain multitudes of life!

2. Breaking the stereotype – Are they all bad? The incredible ubiquity of microbes in our world may seem scary. We tend to perceive them as being dangerous for our health. Indeed, some microorganisms can be quite dangerous. Take for example seasonal influenza or the SARS-CoV-2 coronavirus responsible for the COVID-19 pandemic. Many bacteria can lead to infections in our bodies, and even fungi can cause us discomfort or harm. It is of course important to protect ourselves from harmful microbes. The question is: how? Traditional approaches to hygiene such as regular hand washing and bathing are a good first approach. Preventative measures based on sound scientific research are also important - these include getting regular vaccinations to prepare our immune systems against infections. In cases of serious bacterial infection, antibiotics can be life-saving. It is when we take any of these measures to an extreme that more serious problems can begin to arise. The overuse of soaps and harsh cleaning chemicals, applied too frequently or liberally, can result in skin irritation or even chronic dermatitis. We know too that the excessive use of antibiotics in society can lead to antibiotic-resistant strains of bacteria that can cause fatal disease.

So how do we move through our lives without getting infected and becoming sick? Consider those defenses we did not invent - defenses that our bodies have evolved over millennia of interactions with tiny microbial cohabitants. The human immune system is a complex work of wonder, and one that we do not yet fully understand. As parents, it is of course a top priority to keep our children safe. We try to prevent our children from eating dirty food, touching dirty objects, and getting dirty in general. If we could, perhaps some of us might even entertain the idea of keeping our children in a protective bubble. At face value, this seems like the perfect solution to protecting our children from harm.

Even if we could place our children in a sterile, protective bubble, we would never isolate a child to the extent that they can no longer interact with the world around them. How would they experience new things? Make new friends? Learn new skills? Why, then, do we also entertain the idea of keeping our children in an entirely sterile environment, devoid of microbial life? As we well know, experiential interactions are an important part of early childhood development. Now, scientific research is beginning to reveal that the same may be true for the development of the immune system in early childhood. As the catchphrase now goes, “dirt is good for you!”.

Of course, it is important to maintain a healthy environment and there is a reason that antimicrobial products exist. There are certainly microbes that we would rather not encounter. However, our attempts to disinfect our homes, destroy all unwelcome life, and avoid the microbial world often equate to throwing out the baby with the bathwater. There is just no way you can avoid microorganisms in your life - and we shouldn’t! A balanced relationship with the microbes in our environment is natural and healthy. The following conversation points will cover the topics of why we need microbes, how they serve us and our children, and why developing a healthy relationship with these cohabitants is important for the wellbeing of our families and the planet.

Key points concerning the importance of microbes in our everyday lives

1. ***Exposure to microbial life during childhood is a key variable in the development of a healthy immune system.*** From the moment of birth, children are exposed to microbes that begin to interact with their bodies. Microbes from the mother cover a baby during the birthing process and start to establish a relationship with the child's immune system, communicating and working with it to provide important services. These include proliferation of harmless bacteria on the skin, which can help prevent infection by harmful bacteria in the environment, and colonization of the gut by bacteria that produce essential nutrients our own bodies cannot synthesize.

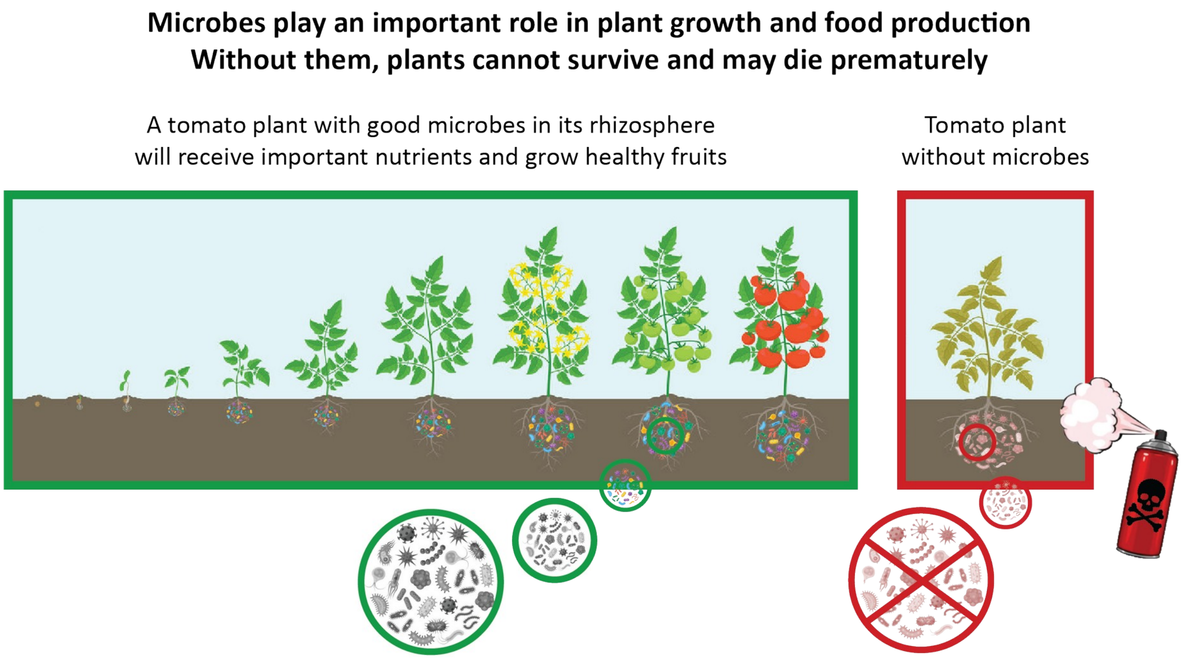
In fact, a mother's breast milk contains important molecules that the baby itself cannot digest, but rather, that "feed" important microbes in the gut (commonly referred to as the gut microbiome), helping to establish a healthy community of gut bacteria in the child. It is now known that development of a healthy microbiome during infancy has incredibly important impacts on health for the rest of our lives. Important bacteria that are commonly found in the human gut include (but are not limited to) *Lactobacillus*, *Bifidobacterium*, and *Streptococcus* species. Perhaps you have heard of *Escherichia coli* (*E. coli*)? Many people do not realize that this microbe is in fact a common constituent of the gut microbiome in healthy humans, which brings us to an important point: whether a microbe is beneficial or harmful is often context dependent and strain specific. In our gut, *E. coli* provides important functions for our health, including producing the essential vitamins B and K12 and increasing the uptake of iron from our food sources.

2. ***The opportunity to interact with the natural world free from fear of 'germs' is important for physical and mental development in children.*** From infancy onward, our immune systems are continually developing and 'learning' how to interact properly with the world around us. With increased efforts to sterilize the natural world, and isolate us from it, during the 20th and 21st centuries, the human population has experienced a dramatic increase in allergies and autoimmune disorders, driven in large part by immune systems that have not been allowed to properly form and adapt. We have also experienced a dramatic decrease in the microbial richness of our intestinal microbiota (which we will discuss later). Scientific evidence is making it clear that there are negative effects of reduced interaction with microbes on our physical health and that of our children. It is also important that we understand the psychological impacts of imposing restrictions on childhood development for fear of 'germs'. Children derive great benefit from playing outside and exploring the natural world around them. Unstructured outdoor play not only improves physical health, but also increases sensory awareness and attention span, and improves cognitive, social, and spatial awareness. Taken as a whole, the opportunity to play outdoors, interact with nature, and get dirty offers far more benefits than risks to physical and mental health during early childhood development.

3. ***The human diet is intimately connected to microbial life.*** Humans have been harnessing the power of microbes to form our diets for millennia. In fact, our modern diet would not exist without the important services provided by microorganisms. The production of many dairy products, such as yogurt and cheese, is dependent upon fermentation and other activity of bacteria that break down sugars from milk into byproducts that modify its flavor and

texture. Similar mechanisms are required to produce beverages we enjoy, like kombucha, wine, and beer.

Microbes are also important for the plants we harvest and eat. Many bacteria form intimate associations with plant root systems, forming the rhizosphere that facilitates the acquisition of minerals and vitamins needed by plants to grow and flourish. Without these microbes, not only would plants be unable to grow, but we would also not derive many of the nutritional benefits we receive from eating them.



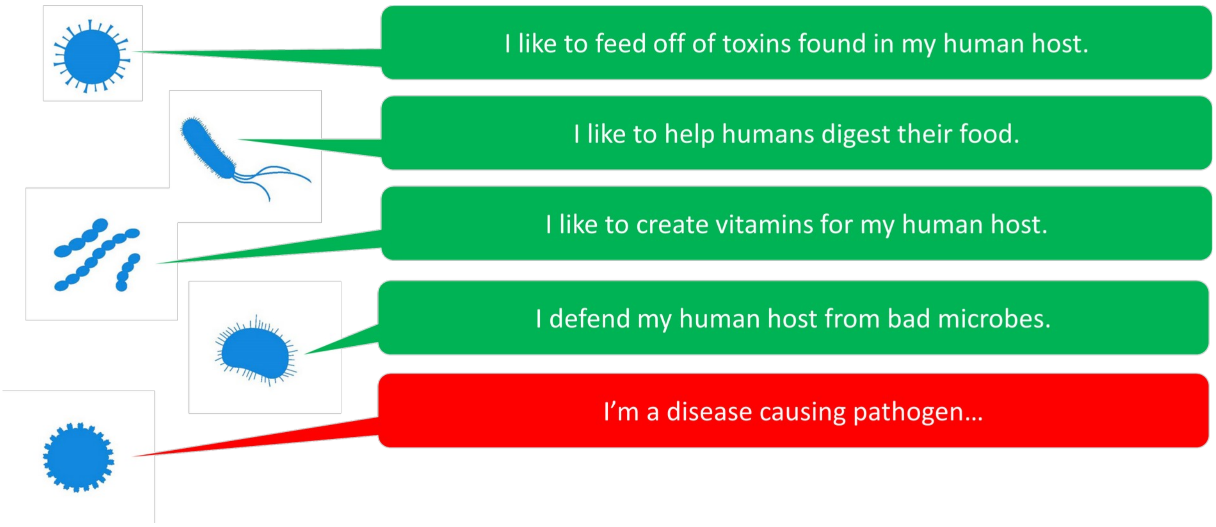
Lastly, as with our own bodies, the bodies of animals we rely on for food are equally dependent on their own species-specific microbial associations to grow and function in good health.

4. ***Microbes provide important services for the planet.*** As long as 3.5 billion years ago, specific microbes known as Cyanobacteria arose on the planet and began producing oxygen. Within another billion years or so, oxygen began to accumulate in a high enough concentration that aerobic life – organisms requiring oxygen – began to evolve. Quite literally, without the microbes, aerobic life on earth would never have come into existence - we wouldn't be able to breathe!

Another important service we often neglect to consider is the role that microbes play in the decay of organic material. When an organism dies, it is microbes that facilitate its decomposition, returning proteins and nutrients to the earth and allowing them to be recycled into new life. Without microbes, the world would be filled with dead organisms and new life would be unable to emerge because there would be no more access to these recycled nutrients.

5. ***Very few microbes cause diseases in humans.*** If you consider the vast diversity of microorganisms that exist on the planet, it becomes clear that the proportion capable of causing harm and disease is quite miniscule. Indeed, given that the number of microbial species has been estimated at more than one trillion, <0.01% of these species are likely to cause harm to humans. Few bacteria present in soil or water are pathogenic or capable of infecting us or our children. In fact, the vast majority of bacteria we encounter during our daily activities are incapable of establishing themselves in or on our bodies. Similarly, microbes found in and on our pets and other domestic animals and livestock are typically harmless and can actually provide benefits to humans by enhancing our immune systems' preparedness for a diverse range of microbial exposures. The more familiar our immune systems are with diverse and harmless bacteria, the less likely they are to overreact. Scientific research has shown that children who are raised with regular exposure to the outdoors and animals are far less likely to develop asthma, for example. Such development of a robust immune system is important for the rare instances in which we are challenged by more nefarious microbes.

6. ***Good microbes can protect us from bad microbes.*** Within our bodies, the establishment of beneficial bacteria in early infancy provides us with an important defense against bacteria that might otherwise cause us harm. By colonizing our bodies early in life, these microbes become familiar to our immune systems, allowing them to serve us by producing vitamins and secondary metabolites our bodies need to function properly. When we harbour a robust microbial community, it becomes more difficult for foreign or potentially harmful bacteria to take root and proliferate in or on us. This early colonization is also why humans harbor distinct and personal microbiomes - like a microbial fingerprint. When we take antibiotics (which may sometimes be necessary), there is potential for us to disrupt our microbiome, causing "cracks" in the community and providing opportunities for foreign bacteria and other microbes to establish themselves and impact our health. This is just one more reason why the use of antibiotics should be carefully considered. With the establishment of a healthy microbiome early in life and the maintenance of a healthy lifestyle that considers our microbes, we are also less likely to ever require antibiotic treatment - a healthy microbiome is the best first line of defense!



7. ***In many cases, infection by a microbial pathogen is the result of humans tampering with nature.*** It might seem like there is a new disease emerging every day, and indeed the number of known pathogens has been steadily increasing throughout history. This is due in part to our improved ability to detect the causes of disease. However, it is also driven largely by the fact that human destruction of natural habitats brings us into closer contact with organisms our bodies are not used to, triggering severe immune responses. Take for example emergence of the SARS-CoV-2 coronavirus responsible for the terrible COVID-19 pandemic. We now know that wild animals are the natural hosts for coronaviruses, and it is the intrusion upon their habitats and harnessing of wildlife for food in tightly packed markets that has led to the 'spillover' of this virus into humans, where it causes terrible disease. Other spillover events from natural wild populations into humans are responsible for diseases like HIV, Ebola, Zika, and rabies, to name just a few.

The industrialization of the food industry also crowds many individual animals into small spaces that allow pathogenic microbes to quickly spread and cause disease and contamination. Within these industries, the widespread application of antibiotics to reduce disease has had trickle down effects that include the emergence of drug-resistant bacteria.

Lastly, research has shown that urbanization, which to some extent represents the replacement of microbe-rich soil, and the microbe-rich air that blows off it, by microbe-poor concrete, reduces microbial diversity among humans.

As we have discussed previously, excessively sterile lifestyles – living in a bubble – leaves our immune systems ill-prepared for exposure to new microbes when we do encounter them. The overprocessing of food has also modified the urban human gut microbiome to be more simplified in its community composition, compared to that of humans leading more rural or hunter-gatherer lifestyles.

Concluding remarks and the science behind the details

1. ***How do we study these microbes and why is it important?*** With the advent of new technology such as DNA sequencing and machine learning, we are now able to observe and study the microbial world in a way that was unimaginable to us a little more than a decade ago. Over this short span of time, we've already made some groundbreaking discoveries regarding just how important these microbes are to our health and that of the planet. As microbial scientists, we aim to develop an understanding of what microbes occupy the world around us, what they do, and how they are influencing their environment. We do this by identifying microbial species, linking species to specific roles, examining how these microbes change due to their environment, and observing how such microbes can work together to form a community. By studying the biology and ecology of microbes, we can gain an understanding of how they are influencing us and the world, in both beneficial and detrimental ways.

2. **What can we do with an understanding of how they work?** As mentioned previously, we now know that each of us carry a unique and distinct microbial community, which can influence our physical and mental state of being. However, we have also found evidence that our microbiomes are not fixed. Experiments involving transplanting microbiomes between individuals have revealed surprising changes in a host's behavior and physical composition. This suggests that we are not stuck with our given microbiomes, and that we may be able to change them in order to become healthier and happier individuals!

Expanding this out to the planet, we may be able to use microbes to help cool the atmosphere, or help the planet produce more oxygen, or grow bigger and stronger crops. Even outside of the Earth, there is potential usefulness for microbes. One scientific idea discussed in the space community is the suggestion of microbial colonization of extraterrestrial environments to terraform inhospitable planets and make them more suitable environments for life.

Microbes are a dominant force in our world. And through studying and learning about microbes, we can improve our relationship with these organisms. Akin to how we cultivate a garden – fostering the plants we desire and weeding out the ones we do not – we can aim to use the knowledge gained from microbiology to cultivate microbes in ways that can benefit not just humans, but life in all its forms on the planet.

Potential Implications for Decisions

1. ***Individual*****:** Understanding by caretakers of the role of microbes in childhood health and development should lead to
    a. Reduced usage of counterproductive cleaning products?
    b. Taking infants (and older children) into green spaces to expose them to diverse microbes, in order to facilitate immune development and reduce allergies and autoimmune disorders associated with dysbiosis?
    c. Acquiring a companion pet, like a dog, that increases exposure to diverse microbes?

2. ***Community*****:** Increased awareness of the ecosystem and functional services provided by microorganisms in the environment should drive
    a. Increased appreciation for food sources

   b. More educated decision-making by consumers of microbial-derived products
   c. Increased interaction between people and utilization of shared outdoor spaces

3. ***Policy*:** Attention to links between resource use, environmental sustainability, and emergence of disease should inform
   a. The widespread application of antibiotics in industrial farming
   b. Deforestation, urbanization, and development decisions that bring humans into close contact with wildlife reservoirs of pathogenic microorganisms
   c. Approaches to decontamination in the built environment that support growth of beneficial or neutral microorganisms while suppressing colonization by harmful microorganisms

Pupil Participation

1. ***Class discussion about how we interact with microbes***
   a. What are microbes, and in what ways can they be good or bad for us?
   b. In what ways can we acquire helpful microbes from our environment?
   c. What are some of the services that microbes provide for us beyond keeping us healthy?

2. ***Personal experiences***
   a. What are some things we can do to make sure we interact with good microbes and protect ourselves from bad ones?
   b. What foods do you like to eat and how are microbes involved in making those foods available to us?
   c. What are things we can all do as a society/community to protect the natural balance of good/bad microbes in our environments?

3. **Additional conversation topics for teachers and students**
   a. Would you like to live in a bubble?
   b. What if we just got rid of all the bacteria/archaea/fungi? Could life survive?
   c. How would biological material decay over time? Would we end up with a bunch of dead things all over the surface of the planet?
   d. How would we acquire nutrients effectively from food sources that our body can't break down by itself?
   e. How would we make yogurt, cheese, beer, wine, etc?
   f. How would photosynthesis occur, and how would we then have oxygen?

The evidence base, further reading, and teaching aids

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Glossary

(definitions from www.merriam-webster.com unless otherwise noted)

Aerobic - living, active, or occurring only in the presence of oxygen

Antibiotic - an antibacterial substance (such as penicillin, cephalosporin, and ciprofloxacin) that is used to treat or prevent infections by killing or inhibiting the growth of bacteria in or on the body, that is administered orally, topically, or by injection, and that is isolated from cultures of certain microorganisms (such as fungi) or is of semi-synthetic or synthetic origin

Antibiotic-resistant - Antibiotic resistance happens when germs like bacteria and fungi develop the ability to defeat the drugs designed to kill them. That means the germs are not killed and continue to grow. Infections caused by antibiotic-resistant germs are difficult, and sometimes impossible, to treat. In most cases, antibiotic-resistant infections require extended hospital stays, additional follow-up doctor visits, and costly and toxic alternatives. Antibiotic resistance does not mean the body is becoming

resistant to antibiotics; it is that bacteria have become resistant to the antibiotics designed to kill them. (definition from www.cdc.gov)
Archaea - usually single-celled, prokaryotic microorganisms of a domain (Archaea) that includes methanogens and those of harsh environments (such as acidic hot springs, hypersaline lakes, and deep-sea hydrothermal vents) which obtain energy from a variety of sources (such as carbon dioxide, acetate, ammonia, sulfur, or sunlight)
Bacteria - Microscopic single-celled organisms lacking a distinct nucleus are known as bacteria. They may be shaped like spheres, rods, or spirals. They inhabit virtually all environments, including soil, water, organic matter, and the bodies of animals. Many bacteria swim by means of long whiplike structures called flagella. The DNA of most bacteria is found in a single, circular chromosome, and is distributed throughout the cytoplasm rather than contained within a membrane-enclosed nucleus. Though some bacteria can cause food poisoning and infectious diseases in humans, most are harmless and many are beneficial. They are used in various industrial processes, especially in the food industry (for example, in the production of yogurt, cheeses, and pickles).
Biology - a branch of knowledge that deals with living organisms and vital processes
Cyanobacteria - any of a major group (Cyanobacteria) of photosynthetic bacteria that are single-celled but often form colonies in the form of filaments, sheets, or spheres and are found in diverse environments (such as salt and freshwater, soils, and on rocks); responsible for producing oxygen and enabling aerobic life to evolve on the planet Earth.
Decay - to undergo decomposition; to separate into constituent parts or elements or into simpler compounds.
DNA sequencing - the process of determining the nucleic acid sequence – the order of nucleotides in DNA. It includes any method or technology that is used to determine the order of the four bases: adenine, guanine, cytosine, and thymine.
Ecology - a branch of science concerned with the interrelationship of organisms and their environments
Eukaryote - any of a domain (Eukarya) or a higher taxonomic group (Eukaryota) above the kingdom that includes organisms composed of one or more cells containing visibly evident nuclei and organelles. All plants and animals are eukaryotes.
Fermentation - The enzyme-catalyzed anaerobic breakdown of an energy-rich compound (such as a carbohydrate to carbon dioxide and alcohol or to an organic acid) by the action of microorganisms (such as bacteria or yeast) that occurs naturally and is commonly used in the production of various products (such as food, alcoholic beverages, and pharmaceuticals) especially by controlling microbial enzymatic activity.
Immune System - The bodily system that protects the body from foreign substances, cells, and tissues by producing the immune response and that includes especially the thymus, spleen, lymph nodes, special deposits of lymphoid tissue (as in the gastrointestinal tract and bone marrow), macrophages, lymphocytes including the B cells and T cells, and antibodies
Machine learning - the process by which a computer is able to improve its own predictive performance by continuously incorporating new data into an existing statistical model
Microbiome - a community of microorganisms (such as bacteria, fungi, and viruses) that inhabit a particular environment and especially the collection of microorganisms living in or on the human body
Pathogenic - causing or capable of causing disease
Organic - relating to or derived from living matter involving carbon
Strain - A strain is a genetic variant or subtype of a microorganism (e.g., a virus, bacterium or fungus). For example, a "flu strain" is a certain biological form of the influenza or "flu" virus. These flu strains are characterized by their differing isoforms of surface proteins. New viral strains can be created due to mutation or swapping of genetic components when two or more viruses infect the same cell in nature. Microbial strains can also be differentiated by their genetic makeup using metagenomic methods to

maximize resolution within species. This has become a valuable tool to analyze the microbiome. *(www.wikipedia.com)*

Vaccination - A vaccine is a biological preparation that provides active acquired immunity to a particular infectious disease. A vaccine typically contains an agent that resembles a disease-causing microorganism and is often made from weakened or killed forms of the microbe, its toxins, or one of its surface proteins. *(www.wikipedia.com)*

Virus - any of a large group of submicroscopic infectious agents that are usually regarded as nonliving extremely complex molecules, that typically contain a protein coat surrounding an RNA or DNA core of genetic material but no semipermeable membrane, that are capable of growth and multiplication only in living cells.