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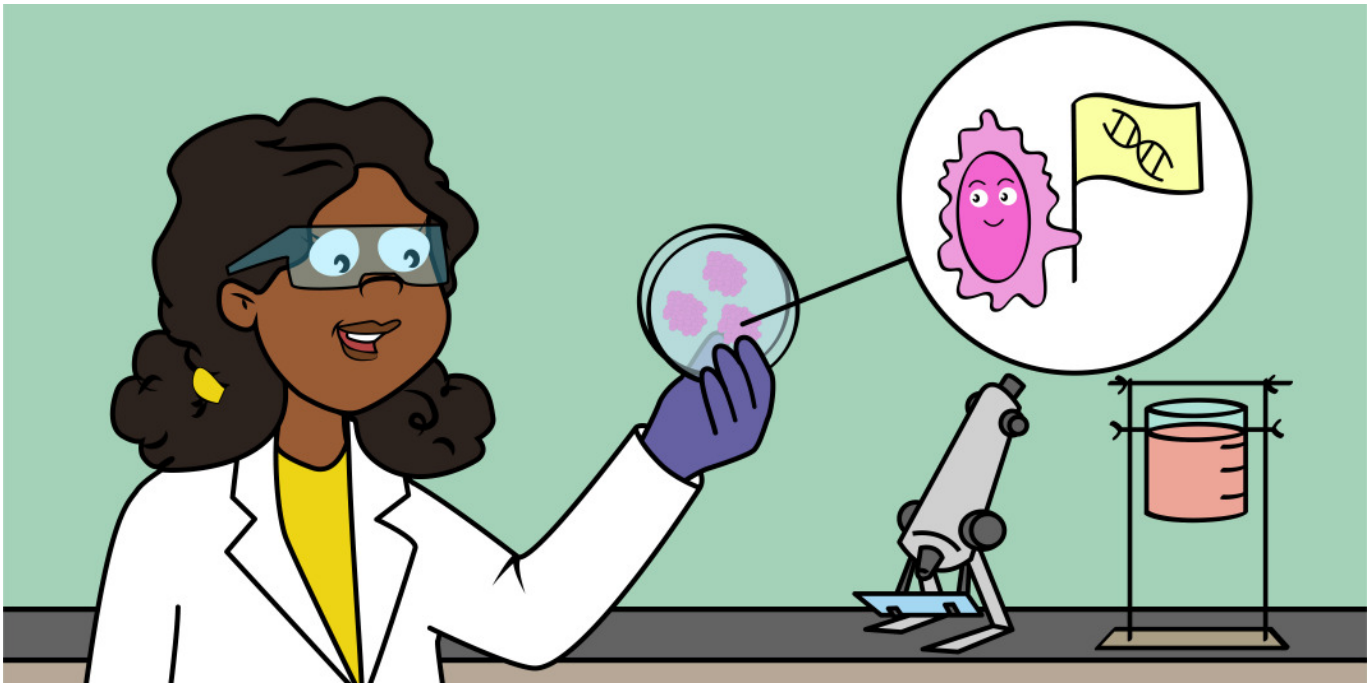

HOW CAN WE USE DNA TO "SEE" INSIDE MICROBES?

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AGE: 11

Have you heard of bacteria and viruses? They are a part of a field of science called microbiology, which is the study of small organisms that cannot be seen with the naked eye. These tiny organisms are often called microbes or microorganisms. The scientists who study them are called microbiologists. Microbes are important to study because there are many living in us and around us. Some microbes can make people sick, but the majority do not harm us, and some can even help us. Some microbes can also help the environment and others can be used to treat and prevent diseases. Since we cannot see these small creatures, there are special tools scientists use to study them. In this article, we will discuss how scientists can study microbial DNA to make advances in medicine and environmental science.

MICROBES COME IN ALL SHAPES AND SIZES AND LIVE ALL AROUND US

Microbes are tiny organisms that cannot be seen with the naked eye. Microbes include bacteria and archaea (simple, single-celled organisms), eukaryotes (more complex cells that are similar to the cells

of plants and animals), and viruses (very small particles that can only multiply inside another organism). Microbes come in many shapes and sizes. They can be round like a ball, long and rod shaped, or even shaped like a spiral. Some microbes have tails called flagella that help them move. Microbes live all around us. There are millions of microbes in a drop of seawater and billions in a teaspoon of soil. There are more microbes on a person's skin than there are people on the planet!

MICROBES CAN MAKE YOU SICK BUT OTHERS KEEP YOU HEALTHY

Some microbes make us sick, while others can be helpful. Microbes that make us sick are called **pathogens**, and pathogens can include either viruses [like influenza, which causes the flu [1]; or SARS-CoV-2, which causes COVID-19] or harmful bacteria (like *Streptococcus pyogenes*, which causes strep throat; or others that cause ear infections or food poisoning). When pathogens enter our bodies, sometimes our bodies can recognize the dangerous microbes and fight them off. Other times, when our bodies can not fight off the infection, doctors will prescribe medications such as **antibiotics**, which can kill bacterial pathogens.

PATHOGENS

Microbes that can make humans sick.

ANTIBIOTIC

A medication used to treat bacterial infections.

Not all microbes make us sick. Some bacteria are used to make foods like bread, yogurt, and chocolate. Other helpful bacteria live on our skin and inside our stomachs and intestines. The collection of microbes that live in and on our bodies are referred to as our **microbiome**. These microbes help us stay healthy by fighting off harmful bacteria. Some bacteria can help us digest foods so that our bodies can use the nutrients to grow. Other bacteria in our intestines can even make special chemicals that are sent to the brain and affect our moods.

MICROBIOME

All the microbes in a particular area, for example in the human body.

HOW DO MICROBIOLOGISTS STUDY MICROBES?

Considering how abundant microbes are, it is interesting that they cannot be seen with the unaided eye. Scientists can use microscopes to look at magnified images of small organisms. For example, if you took a sample of river water (just a few drops is all you need) and looked at it under the microscope, you would see many different types of microbes, such as bacteria swimming around with flagella. Microscopes allow scientists to see the size, shape, and number of microbes in a sample (Figure 1).

Scientists can also culture microbes to study them. Culturing means growing microbes in the lab. Scientists begin by placing a small sample of the microbe in a special dish or tube filled with the nutrients the microbe needs to grow and multiply. Once the microbes have multiplied enough, scientists can study their characteristics, such as

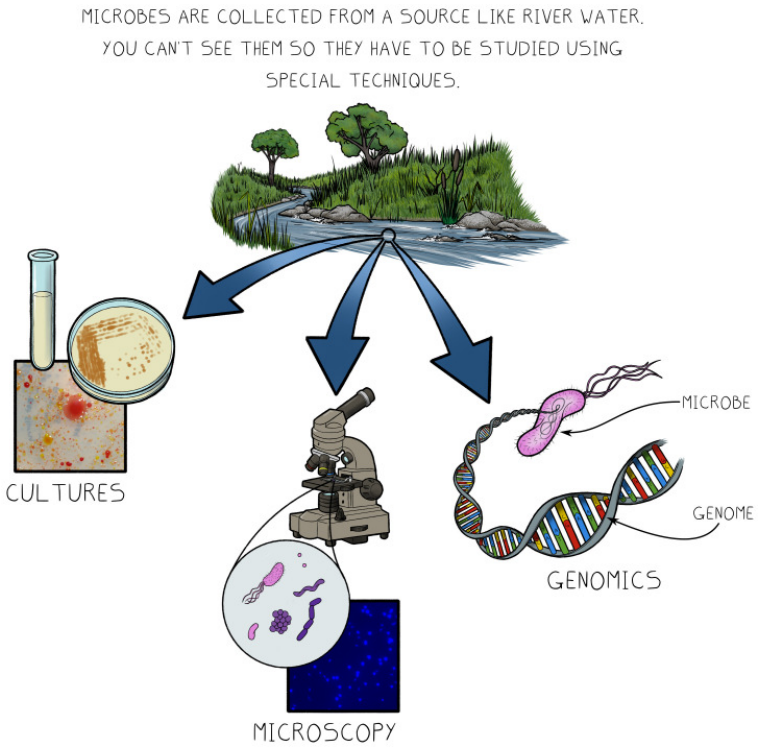

Figure 1

Because microbes are so small, we need special ways to study them. Microbiologists culture microbes to grow them in the lab. They use microscopes to count microbes and see their sizes and shapes. Microbial genomics allows microbiologists to study the genetic material inside the microbes to learn far more about what those microbes can do.

what types of foods they like to eat and what temperatures they like to grow in. Although culturing microbes can teach scientists a lot, more than 99% of microbes on Earth cannot be grown in the lab so we need other ways to study them.

ANOTHER TOOL TO LEARN MORE ABOUT MICROBES

Microscopes are limited because they only show the structure of cells—they do not tell us about their functions. However, new tools allow scientists to "see" inside microbes. All organisms have a code within their cells known as genetic material. This code helps determine what organisms will look like and what they can do. There are two types of genetic materials, DNA and RNA, made up of special molecules called bases (A, C, G, T bases for DNA and A, C, G, U bases for RNA). The bases line up in various orders and lengths (like a secret code) to form **genes**. The codes from some genes tell the cell how to make certain proteins that do specific jobs within the cell. The collection of all genes within an organism (along with some additional genetic material) is called the organism's **genome**. Bacteria typically have thousands of genes in their genomes. It is helpful to know what each gene can do. By studying a microbe's genome, scientists can better understand what that microbe might look like, what it does, and how it might impact the environment and human health.

GENE

A short stretch of genetic material that contains information for a specific function.

GENOME

The complete set of genetic material (DNA or RNA) in an organism.

HOW ARE GENOMES STUDIED?

Microbial genomics is the name of the scientific field that focuses on the genomes of microbes. Genomes are studied by determining the order of bases through a process called **DNA sequencing**. First, scientists pull the genetic material out of the microbial cells and break it into smaller pieces. Then they use specialized equipment to "read" the order of the bases. Scientists then use computers to put the genome pieces back together in the right order through a process called assembly. Once the genome is sequenced and assembled, computer programs are used to predict each individual gene in the genome. The gene sequence is compared to large databases containing gene sequences from other microbes. The similarity of an unknown gene to a known gene in the database helps scientists make a hypothesis about what an unknown gene does. For instance, if the sequence of a new bacterial gene is 99% similar to a known gene that helps bacteria swim, then we can hypothesize that the new bacteria may be able to swim, too.

MICROBIAL GENOMICS

The field of study that uses genome sequences to learn more about microbes, such as microbial diversity, evolution, and ecology in medicine and the environment.

DNA SEQUENCING

A lab technique that determines the order of DNA bases (A, C, G, T) over a stretch of DNA.

MICROBIAL GENOMICS IS A USEFUL TOOL IN MEDICINE

The study of microbial genomes has allowed for better diagnosis and treatment of patients. By understanding the function of genes, scientists can determine what causes illnesses and they can take steps to prevent diseases. For instance, microbial genomics can help us understand whether a bacterial pathogen has a gene that makes it resistant to antibiotics [2]. If bacteria are antibiotic resistant, they can keep multiplying (and making us sicker) even when we are taking antibiotics (Figure 2). Knowing that a pathogen can resist some types of antibiotics helps doctors choose the right types of medicines to combat the illness. For example, doctors can not use the antibiotic methicillin to treat the pathogen called MRSA (methicillin-resistant *Staphylococcus aureus*), so they need to use other types of medicines [3].

Microbial genomics has also been useful for helping scientists understand COVID-19. COVID-19 is the disease caused by a virus called SARS-CoV-2 [4, 5]. Scientists study the genome of the SARS-CoV-2 virus to compare it with other similar coronaviruses and to understand which parts of the virus are used to infect human cells. By closely comparing the sequence of SARS-CoV-2 genomes from different people around the world, scientists can determine if the virus is changing over time. These studies are important because they might show that the virus is becoming more infectious or resisting treatment. Scientists also used the SARS-CoV-2 genome to develop COVID-19 vaccines, which help our bodies recognize the virus and fight it off if we become infected.

Figure 2

Antibiotics are designed to kill bacteria or inhibit their growth. However, some bacteria have special genes that help them resist the effects of antibiotics. Those bacteria can continue to grow and multiply, even in the presence of harmful antibiotics.

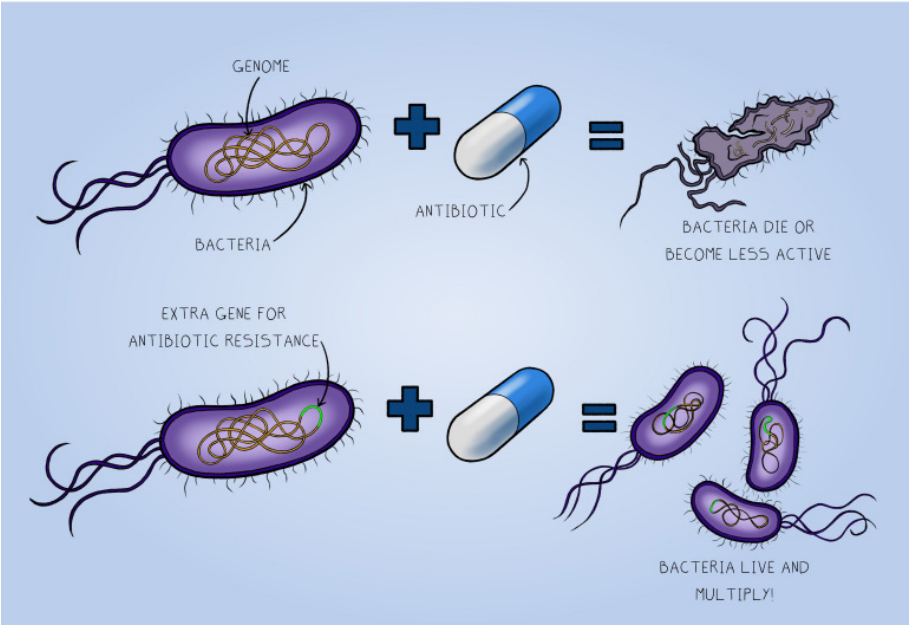

Figure 2

MICROBIAL GENOMICS IS A USEFUL TOOL TO HELP THE ENVIRONMENT

Microbes are found all over Earth in habitats like lakes, rivers, soil, air, ice, and hot springs. Microbes are essential for life on Earth because they make oxygen to help us breathe, provide nutrients needed for plants and animals to survive, and keep our water clean. Scientists can use microbial genomics to learn which microbes are present in the environment and which functions those microbes can perform. This information can help scientists predict whether the helpful microbes in the environment can withstand stress caused by human activity. For instance, if microbes in the environment have antibiotic resistance genes (Figure 2), then they can continue to perform beneficial functions even when antibiotics pollute the environment such as in streams impacted by wastewater or agricultural runoff. Scientist can also study microbial genomes to learn how to clean up contaminated environments. For example, certain microbes can be used to clean up oil spills or toxic industrial sites. Studying microbial genomes can also help scientists make more efficient **biofuels** used to power vehicles in sustainable ways instead of using diesel or gasoline, which are non-renewable energy resources that harm the environment. For instance, certain microbial proteins can be used to improve the speed and cost of biofuel production.

BIOFUEL

Fuel produced by microbes (such as algae) that convert plant matter into fuel that can be used for our vehicles.

SUMMARY

Microbes are important for supporting life on earth, and there are many ways to learn about them. Microscopy allows us to see the size,

shape, and number of microbes; microbial culturing lets us explore a microbe's capabilities and how it reacts to different conditions; and genomics lets us study the structure and function of different genes within the microbe. These methods are all important because, together, they help us understand how each type of microbe can impact human health and the environment around us.

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YOUNG REVIEWER

OLIVE, AGE: 11

My name is Olive. I am a fifth grader and I am homeschooled. I love reading, science, biology, medicine, and taking care of animals, and I hope to study veterinary medicine when I get into university. Our family has one dog, one blue tongue skink, and one busy fish tank. I do Aikido, Judo, Piano, Outschool online classes, and Brazilian jiu jitsu. My hobbies are: knitting, reading books, cooking, reading things on the computer, watching cartoons, and walking our dog.

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I am currently a dental assistant at Children's Hospital of Colorado. I received my Bachelor of Science degree in public health from the University of Colorado Denver. Now I am pursuing a Certificate in Allied and Professional Health Sciences also from CU Denver. In my free time I enjoy traveling and volunteering to serve underrepresented groups in my community.

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Ashley is currently enrolled in the Allied and Professional Health Sciences program at the University of Colorado Denver. She earned a Bachelor of Science degree in Exercise Science with a minor in Biological Sciences from the University of Northern Colorado. In her free time, she enjoys playing soccer, running, and reading.

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Catalina is a fourth-year biology student at the University of Colorado Denver. She is finishing her biology bachelors with a minor in psychology and is hoping to get a master's degree in microbiology. She is a certified pharmacy technician and got her pharmacy technician degree from Ashworth College in 2019. In her free time Catalina enjoys spending time with her family, cooking, painting, and swimming.

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Justin is an undergraduate student at the University of Colorado Denver, studying biology, chemistry, and neuroscience. He works in a neuroscience research laboratory, volunteers at a local hospital, and works as a learning assistant and teaching assistant at his university. He plans to apply to medical school and work toward becoming a surgeon. When not studying or working, Justin enjoys creating art, photography, and taking care of his plants and pet corn snake.

ANNIKA C. MOSIER

I am Annika Mosier and I am Professor at the University of Colorado Denver. My love for microbes started in high school when an amazing teacher opened my eyes to the invisible world all around us. After that, I continued to learn more about microbes in college and in graduate school. Now I teach college students about microbiology. I also have a research lab where my students and I study microbes in the environment. We are exploring which microbes are found in nature, what they are doing, and how they are impacted by environmental change such as antibiotic pollution. *annika.mosier@ucdenver.edu

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