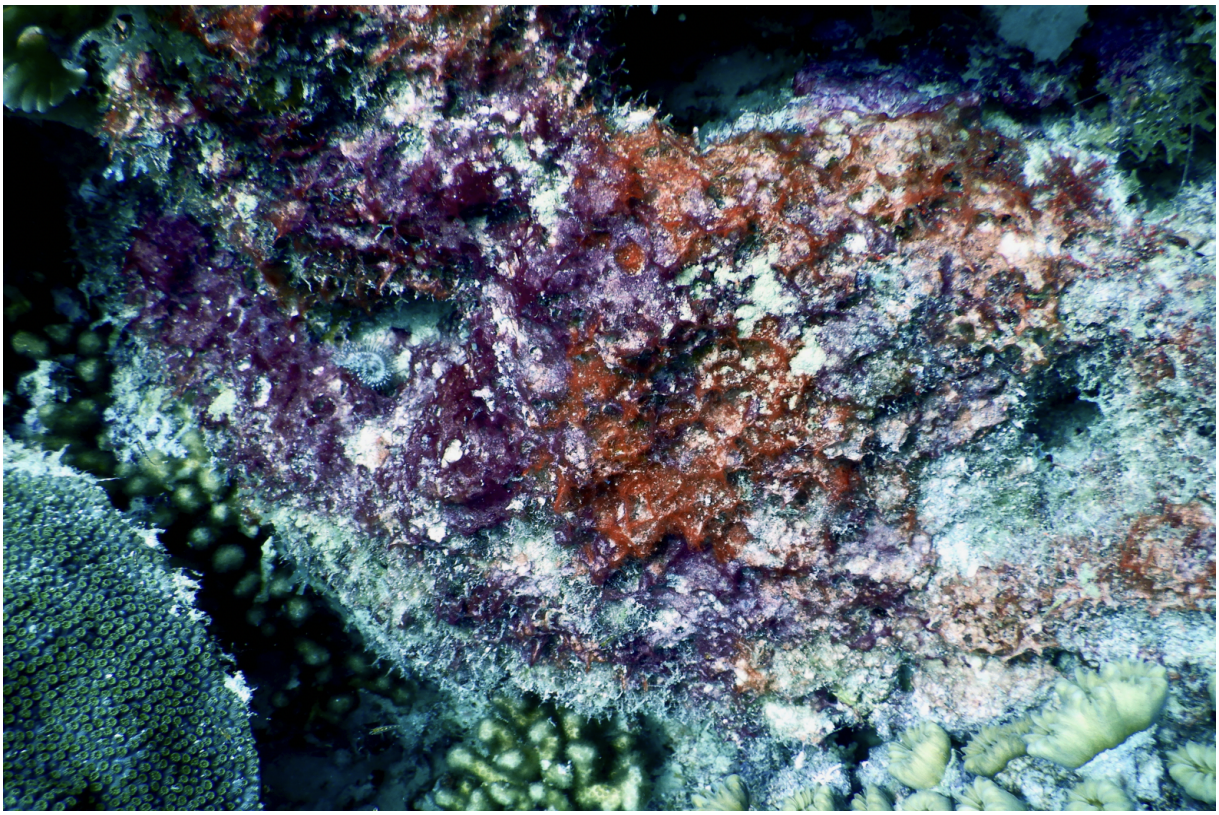
Microbial Competition

Why are the coral turning black?
What type of interactions are at play?



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Nemo's story

Once upon a time, two brightly colored fish were swimming alongside each other and caught each other's eye. They quickly fell in love and got married within a beautiful, glowing coral reef. A few years later, they had a little fish named Nemo. Nemo loved to visit the coral reef where his parents got married and listen to their wonderful love story. His favorite part of the reef was the vibrant colors: pink, yellow, blue, purple ~ and Nemo's personal favorite ~ orange. On Nemo's daily swim to school, he would pass by the coral reef on his way to Mr. Ray's class. Nemo loved to point out his favorite spot in the ocean to which his classmates would ooh and ahh at the lovely colors. One day, out of the blue, Nemo noticed an unfamiliar black spot on his favorite orange coral within the reef. The spot was very small, so he didn't worry too much about it at first and continued his swim to class. Over the next few days, however, the black spot seemed to grow! Nemo was very concerned to see the black spot growing so quickly, so he decided to ask Mr. Ray.

"Mr. Ray, why are there black spots on my coral?" Nemo asked, concerned. Mr. Ray gave a small frown, "Well Nemo, unfortunately, there is something called a microbial mat on the coral. Can everyone say microbial mat?" "Mi-cro-bi-al- mat!" chants the class "Excellent pronunciation" says Mr. Ray, "These microbial mats house tiny little organisms ~called microbes~ that live in layers like a big sandwich. The organisms have been alive for a very long time - they are even older than me!" The class gasps, because Mr. Ray must be a thousand years old, "Well, what are microbial mats made of?" Nemo asks, eyebrows furrowed."Microbes are made of cells, just like you and me. Microbial mats have many types of microbes, like bacteria and archaea, interacting with each other. The mats help with making super important compounds, like carbon and oxygen, and without these, we wouldn't be alive! But you'll learn more about that in highschool..." Mr. Ray smirks.

"Okay..." Nemo thinks, "So why are they turning my coral black?" "Great question, Nemo. These mats sometimes provide a home for bad bacteria. When this happens, the bad guys take over the coral and make it sick. Unfortunately, there aren't very many good coral doctors, so the pretty colors start to turn black."Nemo's eyebrows furrow,"NO! My favorite coral is sick?! But, why did this happen?" Mr. Ray sighs, "I know, Nemo. I'm sorry. Up on the surface, there are lots of things that humans do that change our beautiful home down here - these things cause the seawater temperature to change and also causes lots of pollution. These all contribute to microbial mat changes that can hurt coral."

"People like Darla?" Nemo asked, recalling his adventure on the surface. "Yes. People like Darla. But remember, Nemo, these changes aren't just because of one person. It's the combination of lots of people's behaviors and actions." Mr. Ray pauses, then continues, "Also, the reason it spreads so quickly on the coral is because there are a lot of coral living next door to each other - the bad bacteria can hop from coral to coral very easily." Mr. Ray smiles softly "It's unfortunate, but each human can do their part to reduce pollution and help stop the spread." "So what can WE do to help!?" Nemo exclaims, his mood lifting. "Right now, there's not much we can do, but you can keep asking great questions - and one day grow up to answer them!" Nemo grins,"Rad! I can't wait to be the best scientist ever one day. I am going to stop humans from causing pollution and find a cure for my favorite coral reef!"

"If anyone can do it, it's you, Nemo!" Mr. Ray exclaims, and the class cheers.

Microbial Competition: the Microbiology

1. ***Microbial interactions: the example of microbial mats.***_Microbes, also known as microorganisms, are extremely small living organisms that can only be seen using a microscope. Microorganisms live in many different environments, surrounded by various strains and/or multiple different species entirely. Some examples of microorganisms include viruses, bacteria, fungi, protozoa, and archaea. There are tons of interacting microbial species in the world, which sometimes form thick, multi-layered structures called microbial mats. These mats sometimes proliferate (or grow) depending on the environmental conditions. When they grow near coral reefs, "bad bacteria" in the mat may sometimes jump onto the coral, causing a disease. This disease may spread quickly among corals near one another, which is very bad for coral reef ecosystems.

2. ***Microbial Competition***. Microbial interactions within these mats can be very complex. Many different types of interactions between the microbes occur - the most common of these being competition. Different strains and species of microorganisms compete against each other for nutrients and space. This challenge has caused microbes to change their phenotypes over time in order to compete against the other microbes in the same space. This competition is common but decreases over time as the various genetically distinct microbes learn to coexist.

The specific niches that different types of microbes thrive in play a huge role in their selective forces, which cause certain alleles to become more common within a population over time. This lesson plan highlights the interactions between microbes to better predict future behaviors of microbes. These behaviors can then be applied to real-life settings, giving us insights on how microscopic communities can work with us, rather than against us, in both natural and industrial environments.

Microbes are extremely diverse. They all have different functions and live in various places. In a mat, there are usually many different types of microbes all living together, and they are in a constant battle for food, space, and overall survival - this battle is called competition. If a microbe is strong enough to out-compete the other microbes, it has a high fitness and passes on its genes successfully to the next generation!

3. ***Competition Between Microbes is Widespread.*** When different kinds of microbes live together, they often need to compete for the same resources. There are multiple reasons why microbes often compete with each other namely:

   a. When microbes want the same, limited food source.
   b. When microbes are all living in the same, small space.
   c. When there are a lot of microbes, but not a lot of resources.

The types of microbes that compete with one another is widespread. However, one common trend seen is that, if microbes are related to each other, they are more likely to compete because they want the same type of food, habitat, and other resources. They are also likely to have similar competitive strategies.

4. ***Competitive Phenotypes & Strategies.*** Microbes compete with each other both directly and indirectly. In indirect competition, microbes compete to get the resources they need without

directly coming in contact with one another. For example, some microbes may have phenotypes that contribute to them being faster when collecting resources. This type of phenotype allows them to take all the resources they need first, leaving fewer nutrients for slower, less efficient microbes. Microbes may also indirectly compete for the best location to live in. By establishing themselves in this perfect location, they take up space and exclude their competition from entering the same space.

On the other hand, in direct competition, microbes physically clash against each other - damaging one another. A defense mechanism that microbes have is their ability to create biofilms, which act as a shield against harmful enemies and environments. Microbes can also release antimicrobial metabolites, which act as poisons, killing their enemies. Microbes with competitive phenotypes allow them to have a large number of competitive strategies and defense mechanisms, making them stronger competitors as well as a larger threat within its environment.

5. ***Consequences of Competition Over Time – Coexistence.*** Local diversity consists of all the species found within a habitat. When multiple species of microbes live in the same area and use the same resources, they will compete with each other. Eventually, the top competitors will be the only ones left in the area: this is called the competitive exclusion principle. Although the competitive exclusion principle is often seen in natural settings, there are still some ways in which multiple microbe species can live together. Scientists have found various hypotheses for this coexistence, a few of these being:

a. The Black Queen Hypothesis. This states that, sometimes, top competitors not only allow other microbes species to exist within the same areas as them, they actually need and rely on these other microbes species in order to survive. One hypothesis why this occurs is because some microbe species lose burdensome genes over time if they no longer have to perform these specific functions for themselves. Therefore, even if the microbes who can perform that specific function aren't good competitors, they will remain in an area because the other microbes need them.

For example, let's say there is a super big, strong, athletic mouse and a super small, weak mouse. The big mouse can fight off all the predators, which also keeps the small mouse safe. However, the small mouse is still taking up space and food that the big mouse could be using for itself. The question is, why does the big mouse keep the small mouse around? Well, the big mouse has grown so big and strong that when it is time to creep into small places for food, it can no longer fit! It used to be able to fit, but the mouse got bigger over time. This is where the little mouse comes into the picture; he can fit through almost any hole, making it larger from the inside until the big mouse can come inside. Similar to the microbes, the small mouse has a function that the big mouse had lost over time. This function (squeezing into small places) is important for the big mouse as well. Because of this, he doesn't chase away the small mouse, and instead, they work together to survive.

b. The Red Queen Hypothesis. Competing microbes often go through many evolving processes. If one species can continue to evolve with another species, they can continue to compete with each other. This leads to coexistence because one species is unable to completely beat out the other species. For example, imagine you bought a new pair of new shoes. With them on, you can run fast and easily beat everyone in a race at recess time. You flew past all the other students! However, the next day another student has even newer, faster shoes than you. You try

your absolute hardest to win, and you both fly past the other students, but unfortunately, the other student pulls through and wins the race. Can you guess what you do? The next day you come in with even newer shoes, and the race begins again. This is similar to microbes evolving in the Red Queen Hypothesis. They have to keep evolving to "keep up" with their competition – in doing so, multiple species can continue to coexist.

6. ***Niche/Temporal Specialization.*** This hypothesis is easy. Microbial species can coexist when either the time periods or physical area in which they exist do not overlap. For example, there could be many species of microbes living on a rock within a river bed. Species 1 only comes out at night and species 2 only comes out in the daytime. These species never run into each other due to this temporal difference, and therefore, they coexist. This specialization may occur over time as species learn when and where they can "come out" and not get killed by other species.

7. ***Concluding Remarks.*** In conclusion, the microbial community is just a multi-species assemblage of microbes living in the same shared environment. Just like us as humans, these organisms need food and other resources to survive and reproduce. Sometimes there are not enough resources in the area, so organisms have to compete with one another for these limited resources. Competition for resources happens for multiple reasons, in both direct and indirect ways. Certain phenotypes will allow for species to have increased competitive and/or defensive strategies – and therefore allow them to out-compete the other species. Over time, however, there have been consequences of competition that allow for increased coexistence between different microbial species.

8. ***A Deeper Dive into Microbial Interactions – Bacteria.*** Bacteria are a specific type of microorganism. Like many other microbes, they often live in diverse, interacting communities. The interactions between different bacteria are important to understanding how bacteria survive and reproduce. Understanding bacteria also has important implications for human health, agriculture, and industry. Across environments, microbes like bacteria can interact with each other and with other organisms in positive, negative, and neutral ways; these interactions are largely dependent on the conditions of the current environment. Despite this, research has found that negative interactions are more common than positive interactions. For example, think of interactions of a family living in a house together. The house is like the environment, there are a lot of factors to consider (food in the fridge, the number of beds and bathrooms). If there is plenty of food and space in the house, you and your family might get along great. However, if your parents have a new baby, there is now less space, so you and your siblings might fight over who has to share a room and who gets the last candy bar. Like bacteria and other microbes, these interactions can shift from positive to negative or vice versa. Now, let's dive into the specifics of these interactions!

Microbial interactions are very varied but there are five main types:

a. Mutualistic (+/+): Both species benefit from the interaction. Example: Oxpeckers (birds) and zebras. Oxpeckers eat parasites and bugs that land on the zebra's back - this helps the zebra stay clean. This is also beneficial to the oxpecker because they can easily find food (zebras are easy to see).

b. Commensalism (+/0): One species benefits and the other species doesn't benefit, but also isn't harmed. Example: A bird making a nest in a tree. The bird receives shelter from the tree. The tree is neither harmed nor benefited by the nest.

c. Predation (+/-): One species benefits and the other one is harmed. One species consumes the other species. Example: Wolves hunt and eat moose. This helps the wolves by providing them with energy in the form of food, but hurts the moose because it kills them.

d. Parasitism (+/-): One species benefits and the other one is harmed. One species uses the other species body (the host) to survive. Example: Tapeworms inside the intestines of a cow. Tapeworms eat the cow's slightly digested food which helps them attain food, but harms the cow through the loss of nutrients.

e. Competition (-/-): Both species/organisms are harmed. Example: multiple bacteria species on a single agar plate competing with each other (and killing each other) for the limited space.

9. ***A Modern Day Implication to Bacterial Interactions***. An important issue relating to bacteria interactions in modern medicine comes from something called antibiotic resistance. Remember how there are bad bacteria out in the natural world that make organisms sick (for example, the bacterial disease that makes Nemo's favorite coral black and sick)? Modern medicine makes antibiotics that fight against these bad bacteria. However, sometimes the bad bacteria can change in response to antibiotics. This usually happens over time, causing the "new" bad bacteria to no longer be killed by the antibiotics, making it resistant. Antibiotic resistance can happen in all types of organisms, including humans, due to an overuse and/or repetitive exposure to antibiotics, which allows bacteria to get familiar with the medicine and find ways to fight against it. Understanding the interactions of different microbes, specifically bacteria, may give us insight into how they learn to resist certain antibiotics. This teaches us more about antibiotic resistance and how to deal with it in the future.

10. ***Concluding Remarks.*** Bacterial species are great for studying microbial interactions. There are many factors that determine whether species interactions are positive, negative, or neutral - some of these factors include the type of species being studied, resource availability, previous interactions, how related the species are to one another, and so on. The interactions between and among species can typically be described as mutualistic (both benefit), commensalistic (one benefits and the other is unaffected), predation or parasitism (one benefits and the other is harmed), or competition (both are harmed). Although the beginning of this lesson focused on competition as a microbial interaction, it is important to be aware of the multitude of interactions that could occur, and how these interactions shift and change depending on the type of microbe, its function, and the ecosystem it lives in.

Pupil Participation

Discussion Questions

1. ***Basic***
    a. How are microorganisms different from other organisms?
    b. Can you name one specific type of microbe/microorganism?
    c. What is an example of a way microbes might compete with other microbes?
    d. What is an example of a phenotype that both a person and microbe might share?
    e. What would happen if a big, fast squirrel wanted the same acorn as a small, slow squirrel? Who do you think would win and why?
    f. You just learned how microbes are diverse, can you think of a way in which people are also diverse?
    g. Can microbial mats hurt coral? How?
    h. What type of interaction is mutualism?
    i. If you were a microbe, what is one thing you would do to avoid bad interactions?

2. ***Advanced***
    a. When might microbes stop competing for resources?
    b. What is one reason why microbes compete? What do **you** compete for?
    c. Can you create another "Black Queen Hypothesis" example?
    d. Do you think microbial interactions might differ depending on the environment they live in. Why or why not?
    e. Do you think competitive strategies or defensive mechanisms are more important? Why?
    f. How might microbes be detrimental within an industrial environment?
    g. Can you think of an example of antibiotic resistance that affects humans?
    h. What are ways the environment might be influencing the behavior of bacteria?
    i. What is the word we used to define a neutral interaction where one species benefits and the other is unaffected? Can you think of an example?
    j. Do you think negative or positive interactions are more common among bacteria in the environment? Why?
    k. What kind of interaction relates to the coexistence of microorganisms? Why do you think this?

Glossary

Word	Definition	Example
Environments	The surroundings or conditions in which a person, animal, or plant lives - typically only composed of abiotic (non-living) factors	A forest is a type of environment with trees, plants, rocks, dirt, and a river.
Strains	Variations (subtypes) of one microorganism species	The flu “strain" is a certain biological form of the influenza or "flu" virus.
Species	A group of similar organisms that can exchange genes with one another.	For example, two different species of animals are cows and pigs.
Microbial Mats	A multi-layered sheet of interacting microorganisms	Microbial mats typically look like a green layer on the surface or at the bottom (benthic) of a marine ecosystem (like an ocean).
Proliferate	Reproduce	In the summer, weeds proliferate on your lawn.
Ecosystem	An environment + all the living (biotic) factors in the same area.	A forest is an ecosystem that consists of trees, plants, rocks, dirt, a river, as well as birds, insects, small mammals, and large mammals.
Compete/ Competition	*Compete:* To strive to gain or win something by defeating or establishing superiority over others who are trying to do the same. *Competition:* The activity of competing	Two students compete with each other to win a race.
Nutrients	A substance or ingredient that promotes growth, provides energy, and maintains life	Food!
Phenotypes	Physical or other detectable characteristics	Green eyes, short legs, freckles, brown hair
Genes/Genetics	How certain traits and characteristics are passed from parents to offspring as a result of DNA	My brown hair was passed down from my mom who also has brown hair. My brother has blonde hair which was passed down from my dad because he has blonde hair.

Coexist	Exist at the same time and/or in the same place	If I can only eat fruit and you can only eat meat, we can co-exist and live together peacefully because we don't have to compete - we want different things.
Niches/Niche	*This is a tricky one. It has a few definitions* An organism's role in the environment, its relationship with all the biotic and abiotic (living and nonliving) factors, and the place where an organism exists comfortably.	A rabbit's niche (job) is to eat grasses which creates open areas for plants to grow in forests.
Selective Forces/Pressures	A selective pressure is any reason for organisms with certain phenotypes to have either a survival benefit/ higher fitness or disadvantage	Limited food resources is a selective pressure in an environment because it causes organisms to have to compete for food. Therefore, the organisms with the best, most athletic, and strong phenotypes are more likely to survive and reproduce.
Alleles	Alleles are variations of a gene that can result in different traits in living things.	There is a "brown eye" allele that genetically codes for a person to have brown eyes.
Population	A group of individuals of the same species living and interbreeding within a given area	All the stray cats in New York City can be defined as a city cat population.
Communities	A group of species that are commonly found together (just biotic/living factors)	Fish, coral, and algae species are all found in a coral reef community.
Industrial Environments	An environment where goods or products are manufactured or where materials are processed	E.g., Medical industry, food industry.
Diverse	Showing a great deal of variety/differences	I like lots of different music genres; the music in my playlist is very diverse.
Function(s)	How something works/ a job	The clock functions well. It always shows the correct time.
Survival/Survive	To live	We all need food, water, and shelter in order to survive.
Out-Compete	To win something by establishing superiority over others	A track runner with longer legs can cover more distance faster - therefore, will be more likely to win races against other shorter track runners.

Fitness	An individual's reproductive success	The fitness of naked mole rat (over 100 babies) is much higher than the fitness of a human (2-5 babies).
Resources	Things in an environment that are needed for organisms to survive, grow, and reproduce	Some resources in an environment are air, water, food, soil, space.
Agar Plate	A circular dish with nutrients to grow bacteria on	A scientist uses agar plates to grow the bacteria in the lab.
Limited	Not many; few	There are 6 kids trick-or-treating but I only have 5 candy bars. The amount of Halloween candy I have is limited.
Habitat	The area and resources used by a particular species	Trees provide shelter to many animals and plants within a habitat.
Competitive Strategies	Ways that a species maximizes the amount of resources it receives. This can be done by being more efficient themselves or reducing the amount of resources their competitors receive.	For example, algae that can grow overtop of other algae because it uses its energy to grow thicker instead of longer (like the other algae).
Indirect Competition	Two species that use the same resource but do not interact with each other	Some cheetahs only come out at night to drink from a water hole - this is to avoid leopards that also drink from that same water hole.
Efficient	Producing a lot with minimum wasted effort/expenses/time	I can do my laundry, clean my room, make dinner, and vacuum the entire house in only 20 minutes. I am an efficient cleaner.
Exclude	To prevent another species from getting a resource/ deny or prevent	The bar only lets people 21+ years old come inside. Everyone else is excluded from hanging out in the bar.
Direct Competition	Two species that use the same resource and fight each other to get it	Two monkeys are both trying to reach the largest banana at the top of a tree. They hit and shove each other off the tree so that they can reach it before the other one does.
Defense Mechanism	Ways for an organism to protect themselves	Thorns on a plant are a defense mechanism from organisms that eats it.
Biofilms	A layer of bacteria on a surface that interact with each other	There can be a layer of sticky biofilm that forms on your teeth when you forget to brush them.

Antimicrobial Metabolites	A defensive strategy of releasing a toxic substance (like poison) to kill enemies	Some types of bacteria become toxic to defend against competitors.
Local diversity	The amount of species in a particular area	The local diversity of a fish within a small pond are other fish species. Invertebrates, and plants (grass and lily pads) in the same pond.
Top competitors	Species that are at the top of the food web, usually do not have any predators themselves	A lion is a top competitor because it has many more prey species than predator species.
Competitive exclusion principle	Two species cannot occupy the exact same niche (use the same resources) for an extended period of time.	Grey squirrels fit better in their environment and were better competitors than red squirrels in Britain. Therefore, over time, more and more grey squirrels replaced red squirrels.
Hypothesis	A plausible and testable guess made by scientists when trying to solve a problem	I hypothesize that you will learn a lot about microbial interactions from this lesson.
Coexistence	Two species that live in the same ecosystem and share resources	My cat and I coexist in the same apartment. This is because he eats cat food and sleeps on his cat tree, and I eat human food and sleep in my bed. There is no competition, so we can easily coexist.
Burdensome gene	A gene whose carriage and expression is resource-costly for the cell/organism. If it is not needed, it may be lost over time	A gene that codes for a tail on a pumpkin is unnecessary. This would be a burdensome gene because pumpkins do not need tails to survive and reproduce.
Evolving/Evolve	Populations that change over time to become better adapted (have beneficial/ useful characteristics) to their environment	Over a long period of time, ostriches evolved to have larger bodies and feet made for running on land.
Niche/ Temporal Isolation	Two species that use the same resource can coexist because they use the resource at different times - can be a form of indirect competition	My roommate gets home before me and cooks at 6PM. I get home at 8PM to cook. We never have to fight over kitchen space.
Multi-Species Assemblage	A collection of multiple species	Many different microorganisms grow in your intestines (gut microbiota).
Reproduce	Passing down one's genes through having an offspring	When a mommy and daddy love each other very much they make babies (reproduce).
Detrimental	When something has a negative effect, harmful	A hot summer day is detrimental to an ice cream cone.

Agriculture	Farmers producing plant and animal food to feed people	Growing corn.
Negative Interactions	Interactions between organisms that are harmful	Two frogs compete for sunlight by pushing each other off a log.
Positive Interactions	Interactions between organisms that are beneficial	Birds/rhinos have a mutualistic relationship. Birds eat parasites off the rhino which provides food for the bird.
Mutualistic	Positive/Positive Interactions in which two species benefit each other	I will help you edit your homework if you help me hand out flyers to my birthday party. Both people benefit - this is mutualistic.
Commensalism	Positive/Neutral Interaction in which one species benefits while the other gains nothing	Whales provide a surface for barnacles to grab onto while not harming the whale
Predation	Positive/Negative Interaction in which one species eats the other for food	The lion preys on the gazelle and eats it.
Parasitism	Positive/Negative Interaction in which one species feeds off the other	A tick parasitizes a dog for nutrients.
Implication	A connection/involvement/consequence	An implication of driving without a seatbelt is getting harmed in a car crash.
Modern Medicine	Current substances/techniques used to treat illnesses	If you break your arm, modern medicine can use a machine called a CT scan to see very detailed images of the broken bone. This will facilitate optimal treatment.
Antibiotics	Substances that kill or inhibit the growth of microbes	Amoxicillin is a type of antibiotic used to treat chest infections/colds.
Antibiotic Resistance	The ability to resist or tolerate the action of an antibiotic, and to grow in its presence.	When we suffer from a bacterial infection, the doctor takes a sample to isolate the bacterium and determine which antibiotic will kill it. Some bacteria are sensitive to different antibiotics, whereas multi-resistant bacteria resist several. It is the doctor's job to find the antibiotic that will kill off the infection.
Resistant Strain	A type of bacteria that is not killed by antibiotics	MRSA is a type of bacterial infection that often is resistant to antibiotics, making it hard to treat.
Overuse	Using something to much/often	I wore the same pair of shoes everyday for 12 years, even when they began to fall apart. This caused my feet to be very sore. I overused that pair of shoes.

Repetitive Exposure	Coming into contact with something more than once	When we want to get a sun tan, we might lie in the sun for several days, even though we know it is not good for us.
Multitude	A large number of/many	There are a multitude of microbes in this world.
Avoid	To keep/stay away from something	You often hide from your mom when she asks you to clean your room.