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A Gardenful of Microbes

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Introduction

Most people associate microbes with a negative connotation. After all, microbes cause deadly diseases and make people sick. However, microbes have many lesser-known positive functions. It is important to teach my students about microbes because microbiology is one of the areas in science that is really untapped. Microbes also are the first form of life to evolve on our planet. About 2.5 billion years ago, cyanobacteria "developed the trick of oxygenic photosynthesis." [1] This adaptation led to increased oxygen levels in the atmosphere, and allowed for life on land to follow even though it would take several hundred million years. [2] Not only are microbes the first form of life, they are the most biodiverse form of life, and they impact every ecosystem on Earth. Microbes are capable of solving problems: cleaning up oil spills, generating energy, eating pollution, eating plastic, eating nylon, metabolizing methane gas, killing cancer, treating depression and anxiety, and reducing acid run-off. [3] There are likely hundreds of thousands of microbes that have yet to be discovered. They exist in every part of the world, and the benefits of the microbial world to environmental and medical problems seem to be limitless. Students need to learn at a young age the potential benefits microbes have to offer.

As a self-contained fourth grade teacher in an urban school system, my students are at the perfect age to learn about microbes. My students are eager to learn. They enjoy hands-on science activities, and are able to work in groups in a semi-independent manner. Unfortunately, due to schedule demands and the emphasis on state testing, science gets minimal attention at my grade level. By combining many science skills as well as language arts and math skills, the time will be well spent.

Rationale

My fourth grade students have a limited understanding of microbes. They know that germs cause sickness and that germs are too small to be seen with the naked eye. They do not know that microbes make up the overwhelming majority of the Tree of Life and live in all environments throughout the world. They do not know that microbes have a huge ecological impact on the world, and that microbes take on many roles in our world including: keeping nature in balance, treating illnesses, and removing pollutants from the environment. According to Bernard Dixon, "The powerful work of microbes in the soil is essential to the existence of life itself." [4] The curriculum unit lays out how the soil food web works and the important role microbes play. Students everywhere need to learn the benefits that microbes provide, and it makes sense to pique their interest while they are young, and while their minds are sponges.

My students enjoy science, but unfortunately due to the demands of testing, the time spent on science has decreased. At my school, we have garden space and a compost bin. Typically second grade uses the garden, since they are not constrained by testing. In this unit, since I have incorporated multiple science standards, I have in essence freed up some time, and plan to take my kids into the garden. Thomas Berry, a world-renowned cultural historian, states, "Teaching children about the natural world should be treated as one of the most important events in their lives." [5] I grew up exploring nature and I am a teacher who is not afraid to get her hands dirty or to touch a worm. As much as my students need this unit, I do too!

I also wanted to write this unit to benefit teachers not only in my district, but also in schools throughout the world. In the United States, there has been a huge movement toward school gardens. A huge part of the movement is related to addressing childhood obesity and healthy eating habits. There also has been a push to buy local whole foods to avoid eating less healthy processed foods. No matter what the reason is behind the movement, there has been an increase in the emphasis placed on gardens and on eating local foods. This unit is designed to build understanding of how nature works to help the garden grow better.

Objectives

A Gardenful of Microbes is a unit designed for fourth grade students. This curriculum unit will encompass the science standards for Life Processes and Living Systems. Within these standards, some key ideas that resonate are: 1) plants and animals in an ecosystem interact with one another and with non-living components in the ecosystem, 2) basic plant anatomy and life processes including adaptations, allow plants to satisfy life needs and to respond to the environment, and 3) natural resources, some of which are plants, animals, and soil. Writing a unit relating to these standards will allow me to incorporate many standards into a real-life comprehensive unit that will demonstrate the intricacies of the world around us. It will teach the students about the beneficial microbes in the garden focusing on the soil beneath their feet.

Background

The background information describes the organisms that comprise the soil food web. I provided a brief description of each, for teacher background, and for information to provide to the students.

Bacteria

Bacteria are the earliest evolved and most prevalent form of life on earth. Bacteria are unicellular organisms whose DNA is not enclosed in a nucleus. Bacteria are so small that "anywhere from 250,000-500,000 can fit inside a period at the end of a sentence." [6]

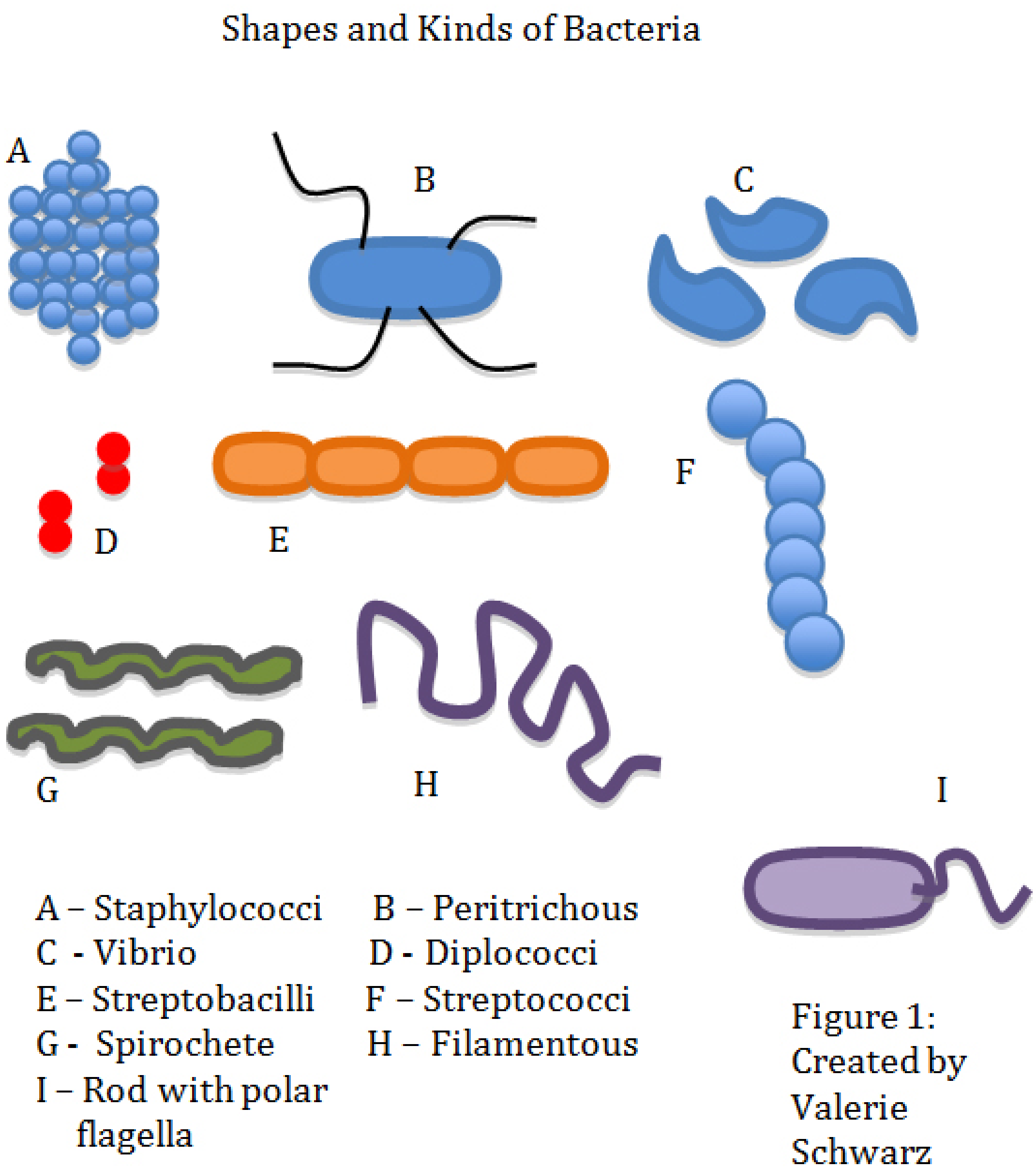

Figure 1: Created by Valerie Schwarz

Microscope pioneer, Anthonie van Leeuwenhoek discovered bacteria in 1676. [7] He described the shapes of bacteria, and even today scientists can identify the distinct categories Leeuwenhoek described. Some of the shapes of bacteria are spheres, spirals, rods, grape-like clusters, rods with flagella, string of spheres, and commas. [8]

Leeuwenhoek also described protozoa and fungi, which are two other classifications of living organisms that are found throughout the world. [9] Fungi and protozoa play key roles in the soil food web.

Fungi

Mold, mildew, yeast and mushrooms are examples of fungi. Scientists have identified "over 100,000 different kinds of fungi." [10] Fungi vary in size from single-celled organisms to multicellular ones, such as mushrooms.

Fungi were once considered plants, but due to their lack of chlorophyll and differences in their cell wall and cell membrane, they are no longer included in the plant kingdom.

Protozoa

Protozoa are microscopic, animal-like organisms. They are either single-celled or live in multi-celled colonies. They have a well-defined nucleus, live in aquatic or moist environments, and are larger in size than bacteria. There are more than 60,000 known species of protozoa. [11] Some of the more common ones are the amoeba, euglena, and paramecium.

An amoeba uses a pseudopod for locomotion or movement, as well as for food collection. Pseudopod means "false foot." The cytoplasm, or the gelatin-like material found inside the unicellular organism protrudes, or oozes, in a direction. The false foot adheres to the surface. When the trailing edge is retracted, the cytoplasm is thrust toward the leading edge, thus pushing the cell forward. The pseudopod is also used for food capture. The pseudopod spreads out, surrounds its food, and then absorbs the food into its cell.

The euglena is a unicellular organism with a single flagella, a whip-like structure that is used to propel the organism through water. A euglena is a type of flagellate, meaning an organism having a flagellum.

A paramecium is a ciliate, a unicellular organism with hair-like cilia. The cilia are used for locomotion and to move food into the organism. Cilia mean "eyelashes" in Latin. When the cilia flutter, or beat, the paramecium moves and directs food into its mouth.

Nematodes

Most nematodes are microscopic. They are round worms that live in salt water, fresh water, and in soil. There are parasitic plant nematodes and free-living nematodes. The nematodes that reside in the soil are mostly beneficial and free-living. There are bacterivores that eat only bacteria, fungivores that eat only fungi, herbivores that are plant eating, and predators that feed on algae and protozoa. [12] They break down organic matter and live near the roots of plants.

Arthropods

Arthropods have exoskeletons as well as segmented legs and bodies. Their exoskeletons are made of chitin. Arthropods generally have three stages of their life: egg, larva, and adult. Many arthropods live all three stages of their life in or on the soil, but others only spend one or two stages in or on the soil. During each stage, arthropods need different resources and fill different niches in the soil food web. The arthropods may be a food source for various organisms depending on their stage in life. For example, a Japanese beetle is a grub during its larval stage and eats mostly grass roots. However, once the grub transforms into an adult Japanese beetle, it flies and eats leaves of trees. Soil-dwelling arthropods shred material in the soil, aerate the soil, and are predators of other organisms, particularly bacteria and fungi.

Earthworms

Earthworms originated in Europe and arrived in the New World with European settlers. [13] Earthworms are a grayish-red in color and have segmented bodies. Earthworms are shredders and aerators of the soil. Their castings are beneficial to the health of the soil.

Mollusks

Slugs and snails are the main mollusks, or gastropods, found in the soil. They have a single large foot. Snails also have a shell, which helps to protect them, especially from dehydration. Mollusks in the soil are shredders that help to speed up the process of decomposition.

Small animals

Moles, voles, birds, and reptiles help to move organic material and also microorganisms to different locations. Small animals are often a sign of a healthy soil food web.

Soil Food Web

The soil contains an intricate, interwoven food web consisting of the organisms previously described. As with all food webs, the energy comes from the sun. A plant absorbs sunlight and uses energy from the sun in the process of photosynthesis. During photosynthesis, a plant produces its own food. Much of the energy that results from the process of photosynthesis is actually used by plants to produce chemicals that are emitted by the roots as exudates. Root exudates are made up of carbohydrates and proteins. The exudates exist in the rhizosphere, which is the area of soil that surrounds the roots and extends about 1/10 of an inch from the roots. [14] Plant–bacterial interactions in the rhizosphere are the determinants of plant health and soil fertility. [15] The plants and the microorganisms constantly influence the rhizosphere.

Plants can manipulate the food web based on the exudates they produce. The exudates attract beneficial bacteria and fungi, thus comprising the lowest level of the food web. Protozoa and nematodes are also attracted to the rhizosphere and feed off of the bacteria and fungi. Larger microorganisms, such as protozoa and nematodes, consume bacteria and fungi while excreting what they don't use as waste. The roots absorb the waste that was excreted as nutrients. [16] Protozoa and nematodes can be thought of as "fertilizer spreaders," since they release the nutrients that were immobilized by the bacteria and fungi. [17] Thus the rhizosphere is the absorption site of root nutrients. In summary, microbes are beneficial to the soil food web because they hold nutrients in the soil and keep them from leaching out of the soil. Another reason why microbes are essential is because they transform nutrients into a form that plants can use.

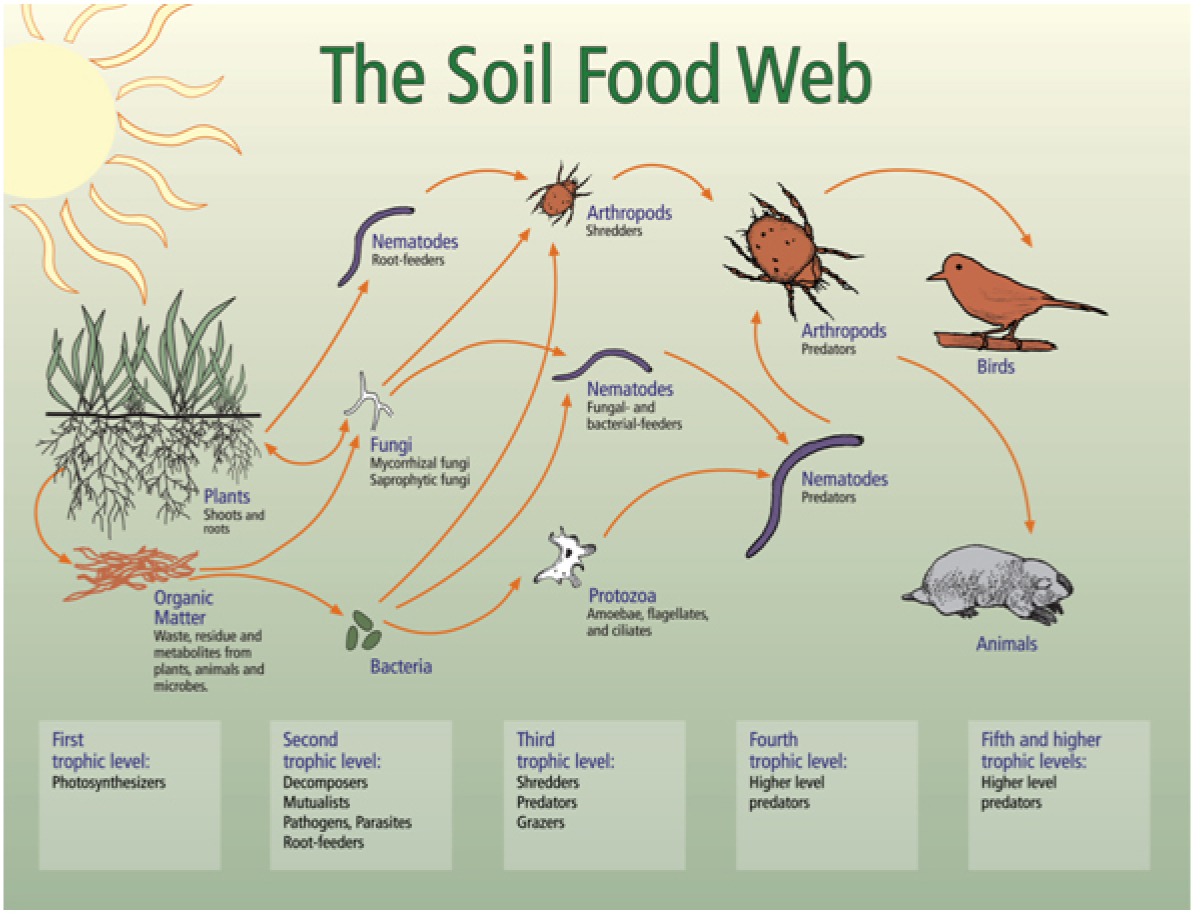

Figure 2: Courtesy of SWCS
Soil and Water Conservation Society (SWCS). 2000. Soil Biology Primer. Rev. ed. Ankeny, IA: Soil and Water Conservation Society.

A healthy soil food web provides protection for plants against harmful microorganisms. Bacteria and fungi coat the surfaces of roots and leaves, making it difficult for harmful bacteria to attach. [18] The coating also protects the plant from pollutants. However, if the population of bacteria and fungi decrease in number, the plant becomes more vulnerable to harmful pathogens and is more likely to come under attack. [19]

Soil Structure

Living organisms improve the structure of the soil. Bacteria produce a slime enabling them to move and to attach to substances. An example that Kristin Ohlson describes in her book, *The Soil Will Save Us*, is how the bacteria in our mouths create glue from scum and plaque in order to adhere to our teeth. [20] Bacteria in the soil make "glue" using the carbon-rich sugar from plants. This glue, or slime, is used to attach the bacteria to a piece of silt, clay or sand, so they are not washed away with the water. Then the bacteria attach to other pieces of the soil and create an aggregate that protects the bacteria from predators. The aggregates create small pockets in the soil that can hold air and water. [21] The aggregates created by the bacteria are the smallest ones found in the soil. Fungi create larger aggregates by joining the bacterial aggregates together. A type of fungi called glomales produce glomalin, a sticky protein that binds to the soil particles. [22] When protozoa and nematodes move through the soil, they create pathways of different sizes. Arthropods create even larger pathways and spaces where water and air can collect and move through the soil. Worms improve the soil structure through their movement, and also from their worm castings or their waste. Worm castings are aggregates, which are visible and easily identifiable in the soil. [23]

The aggregates create a healthy soil structure that impacts the movement of water and gas through the soil food web. Soil can range in color from a dark brown, red, yellow, to light grey. The color indicates the mineral content and can possibly provide insight into the environment. Grey soil indicates anaerobic conditions, meaning without oxygen. Dark brown soil indicates a highly organic soil, which is associated with a healthy ecosystem. [24] Good soil structure not only improves the amount of water, gas, and nutrients the soil can hold, but also makes the soil better able to handle heavy rain as well as drought conditions. [25]

A healthy soil food web has a great diversity of species calling it home. "A handful of soil can contain one trillion bacteria, 10,000 protozoa, 10,000 nematodes and 25 kilometers of fungi." [26] The microorganisms in the soil need air and water in order to live. Therefore another sign of healthy soil is loose soil that contains many aggregates and pathways in the soil. When the soil is more compact, it will not retain as much air and water. A small change, or perturbation, of the soil can have a snowball effect on the soil food web. If the soil cannot hold enough air and water, the population of bacteria and fungi may be reduced. If the populations of bacteria and fungi are reduced, the protozoa and nematodes may not be present as consumers of these food items, thus further decreasing the pathways in the soil. Without the protozoa and nematodes, the arthropod and earthworm populations may also shrink in number. Thus, the problem of a compact soil perpetuates and it becomes increasingly more compact. With fewer aggregates, the soil cannot hold water. Therefore it becomes drier and more tightly held together, further diminishing the biodiversity in the food web.

Bacteria and fungi not only help to create aggregates and impact the soil structure, but they also play another crucial role in the soil food web. Fungi and bacteria are the primary and secondary decomposers of the soil food web. Without fungi and bacteria, humans would be buried alive. Bacteria decompose plants and animals and immobilize, or lock the nutrients inside of their bodies. The nutrients are released when the bacteria die or when the bacteria are consumed by another organism. Fungi decompose chitin, or the shells of insects, cellulose, bones of animals, and lignin, which is found in cell walls and algae. These materials are more difficult to break down, but fungi are equipped for this job.

As in any food web, organisms lower in the web become prey for other organisms in the web. Bacteria and fungi are prey to protozoa and nematodes. Protozoa consume bacteria, other protozoa, and sometimes fungi. Nematodes, or non-segmented worms, consume bacteria, fungi, protozoa and other nematodes. These are consumers in the soil food web and predators of bacteria and fungi. Protozoa and nematodes are the prey of insects and spiders, or the arthropods that live in the soil. Snakes, birds, and other animals then consume the arthropods.

Human Impact on the Soil

Humans impact the soil in positive and negative ways. The use of chemicals provides benefits in the short term. However, through my research, these chemicals ultimately change the ecosystem, and have harmful effects on the ecosystem and the environment.

Fertilizers

The practice of chemical farming has only been used for about 50 years. Ironically, "out of the chemistry of war and bombs came the first synthetic nitrogen fertilizers." [27] When one considers fertilizers, bombs, and war together, one can only wonder how using chemical nitrates could possibly be beneficial for our food sources and our environment.

For years the soil was viewed as a combination of chemicals instead of as a living system. When the soil is viewed as chemicals, it seems perfectly logical that adding chemically-synthesized nitrogen would enrich the soil. However, when one views the soil as a living system, and analyzes the small perturbation created by the addition of chemical nitrates, suddenly it seems as if it contradicts everything we know about ecosystems. More specifically, when a chemical nitrate is added to the soil, the nitrates are close to the roots. The plant's roots can absorb the nitrates without giving up any carbon. In nature, a plant emits exudates from its roots, similar to when people sweat. Exudates contain carbon, vitamins, and other chemicals to attract bacteria and fungi. The plant's exudates feed the bacteria and fungi in exchange for plant-soluble nitrogen. When a chemical nitrate is used, the plant does not have to put out exudates, therefore the plant does not attract microorganisms. Without the microorganisms, the biodiversity of the soil food web is diminished. The healthy aggregates do not form, and the soil can hold less air and water. Over time, the soil food web and the soil structure are diminished, making the land more susceptible to disease, floods, and droughts.

Herbicides

Herbicides, also called weed killers, are used to control unwanted weeds. Plants produce exudates that attract the most desirable bacteria and fungi for their development. So, if greater plant variety exists, there will be a greater diversity of bacteria and fungi. Increased species of bacteria and fungi will attract different species of protozoa and nematodes, etc., resulting in the creation of a healthier soil web. Therefore when herbicides are used and kill off species of plants, the soil ecosystem is negatively impacted.

Pesticides

Similarly, pesticides kill plant, fungal and animal pests. Pesticides impact the ecosystem. Eliminating pests reduces the biodiversity of the pollinators, as well as the soil-dwelling insects that move bacteria through the soil. Pesticides also have a negative impact on the health of earthworms. Again, one small change to the ecosystem creates a ripple effect.

Tilling the Soil

At first glance, tilling the soil seems to be a wonderful farming practice. How could loosening the soil be bad? However, the heavy machinery that churns up the soil also decimates the living organisms in the soil by severing their bodies. The fungal hyphae, or white threads of fungus, that spread throughout the soil are also shredded. Once again, this seemingly beneficial practice impacts the entire soil food web in a detrimental way.

Organic Farming

Organic farms have strict requirements and guidelines in the United States. By using organic practices, farmers greatly reduce the impact humans have on the soil and the ecosystem. The USDA clearly defines some organic farming principles that need to be followed. The two principles that are closely related to the soil food web include: 1) preserve natural resources and biodiversity and 2) only use approved materials. Following organic farming principles will help to protect and sustain nature's biological system.

Cover Crops

Cover crops are crops that are planted to prevent erosion and to enhance the soil. Cover plants are also referred to as "Green Manure" or "Living Mulch." Legumes such as alfalfa, peas, clover and beans are used to enhance the nitrogen in the soil. [28] Gabe Brown, a farmer in North Dakota, uses four different types of cover plants for the purpose of having live roots in the soil all year round. "Even a modest two or three species cover crop causes a 90 percent reduction in sediment runoff and a 50 percent reduction in fertilizer runoff into the watershed, and sequesters a metric ton of carbon dioxide per acre." [29]

No-till

Another method to enhance the soil is to avoid tilling the soil. Tilling destroys organisms in the soil including fungal hyphae (the white thread-like fungus that protects the roots), arthropods and earthworms. Tilling also destroys the system of aggregates that has developed because of the healthy food web.

Gabe Brown uses a combination of organic farming, cover crops, and no-tilling methods, and he has results to support the usefulness of these techniques. Kristin Ohlson visited Brown's farm and stuck a metal rod four feet into the soil, which demonstrated the porosity that has developed as a result of his combination of farming techniques. [30] Prior to using these techniques his land could absorb a half-inch of rain in an hour, and 19 years later, his fields absorb eight inches of rain in an hour. [31] Gabe Brown has also seen a tremendous improvement in the texture of his soil.

Strategies

Prior to this unit, my students will have learned the parts of a plant, the parts of a flower, and their functions. They will understand the processes of photosynthesis and reproduction. Next, we will look at the role microbes play in the environment of a plant. I deliberately incorporated numerous science objectives into this unit on microbes to maximize my instructional time. The content areas of science and social studies continue to be limited due to the emphasis on the tested curriculum in math and language arts. In order to combat this problem, and to provide meaningful, rich learning experiences, I intertwined the objectives. It also makes sense because these very same science objectives are intertwined in the real world and do not occur in isolation.

Throughout this curriculum unit, the students will perform hands-on, inquiry-based, and small group collaboration as the strategies for learning. These three strategies are engaging for my fourth graders. These strategies also help to differentiate the instruction so all students can access the curriculum.

We will begin with the roots and the soil. The interactions between organisms that take place in the soil are not only important, but also mostly invisible to the human eye. As a pre- and post-assessment, I want my students to describe what lives in and makes up the soil. I anticipate that most students will only think about the living organisms and organic matter. My students study soil in third grade, so this activity will also give me an informal assessment of their prior knowledge.

Then I will explain that the soil is teeming with life…with millions of microbes. Microbes include bacteria, fungi, protozoa, and viruses. I will provide pictures of microbes for my students to classify and sort. I anticipate that the students will naturally ask questions about the images. As they sort the pictures, they will write down some of their most pressing questions. I imagine the shapes, the body structures and the way the microbes move and eat will be of interest to my students. I want the pictures to draw my students in and to get them interested in the world that resides in the soil.

Next, students will watch a Brainpop video on bacteria and also some clips of videos to answer some of the questions that were generated. We will talk about the different shapes and kinds of bacteria: coccus, spirochete, bacillus (rods), staphylococci (grape-like clusters), rod with polar flagella, diplococci, filamentous, streptobacilli, peritrichous (rod with many flagella), streptococci (string of spheres), and vibrio (comma). It might be fun to make pictures of the different bacteria using their fingerprints. The students will learn that bacteria live both inside and outside of plants. Free-living bacteria that live outside of the plant in the soil are called rhizobacteria. Then we will begin to discuss the soil food web, and what is really happening in the dirt beneath their feet.

Once my students have a basic understanding of bacteria, I will employ more inquiry-based instruction to build their knowledge of fungi, protozoa, nematodes and arthropods.

Working in small groups, each group will have fungi, protozoa, nematodes, or arthropods. The students will develop 5-10 questions that they want to investigate. Using a list of student-friendly links, the students will find and record the answers to their questions. Upon completing the fact finding, students will work with a partner to create an identification card including a picture and basic facts. Students will then share their ID cards with a different group.

My students will work in small groups using the ID cards to write "want ads" representing an organism and describing the type of home and food it seeks. These will be shared with the class. Once my students have a working knowledge of the organisms in the soil, the class will begin to construct a soil food web bulletin board. Each student will choose an organism. Given a rubric, each student will find or draw an image of their organism on the computer and write a brief description. All of the organisms will then be assembled into a representation of a food web. Yarn will be used to show the interrelatedness of the organisms. Throughout the unit, students can add information to the bulletin board.

Then the students will go out into our school garden and, working in small groups, we will conduct a census of the species in the soil (See biodiversity activity below.) In order to further develop my students' higher order thinking skills, we could conduct a second census in a different part of the schoolyard. My students will compare the results and draw conclusions. In an effort to incorporate more inquiry-based strategies, the students will formulate questions about the species they unearth. Then they will seek the answers to their questions using the internet.

Tapping into local resources, it would be informative to invite a guest to speak to my class about the soil food web. Another possibility would be to visit the Rice Center, which is part of Virginia Commonwealth University. The Rice Center is a living laboratory set on 494 acres along the James River. The center provides research and education opportunities and focuses on environmental education.

My students will work in the garden and manage the compost bin throughout the duration of this unit. We will start some vegetable seeds indoors, and then plant them outside in the early spring. Through the work in the garden, my students will encounter many organisms in the soil, and will develop a better understanding of the niches many of the organisms fill.

After learning about the soil food web, I want my students to understand the impact human activity has on the soil food web, particularly applying chemical fertilizers and tilling the soil. Additionally, I want my students to understand some positive alternatives so they can become better stewards of the earth.

Activities

Microbe Sort

Students will be given pictures of microbes to sort and classify in small groups. The students develop questions about the microbes as they sort the images. The sort will introduce the students to the different shapes and modes of locomotion used by microbes and lead to a rich, student-led discussion.

Biodiversity

In small groups, students conduct a census of visible species in the soil. In order to perform this activity, the students dig a 12-inch square in the school garden. As they dig, they place the soil they remove on a tarp. The students then comb through the soil, picking up any living organism that is safe to handle with their bare hand that they see with their naked eye. Plastic cups and sand toys can also be used for picking up the organisms. Posters will be attained to help the students to identify the species found. The class will compile the information, determine if the ecosystem has a variety of species (biodiversity), and make predictions about the population of species that are invisible. For example, if the students find a number of springtails and understand that they eat bacteria and fungi, they can predict that bacteria and/or fungi are in the soil. A few student photographers will capture the images. Students will determine the number of organisms and the diversity of the species found. Students will then graph their data.

The students will repeat this procedure in a different part of the schoolyard. Prior to conducting the data collection, students will analyze the soil and make predictions about the amount of organisms they will find. The results of a different location will be compared using a Venn diagram, and conclusions will be drawn about the health of the soil.

Berlese Funnel

The students, working in small groups will make a Berlese funnel, which is an inexpensive way to extract smaller organisms from the soil. In the teacher resource section, the Youtube video that shows how to make the funnel is listed. The students will construct their funnel using a 2-liter soda bottle, a piece of mesh, and a small cup of isopropyl alcohol. Then a soil sample from the garden will be placed in the funnel and the light source will shine on the soil sample. The students will filter out the organisms, gather their data, and once again, construct a graph to display the data. Students will make predictions about the smaller organisms that are in the soil, based on the organisms that they find with their Berlese funnels.

Protozoa Extraction

The final activity will allow the students to see the protozoa that live inside of termite guts. Using several termites that are found in some rotting wood, or purchased from Carolina Biological, students will extract the protozoa from inside the termite by gently squeezing its body. Using a pipette and mild saltwater, students will prepare a slide. Then students will use a microscope to look at the protozoa. If time permits, the students will draw the protozoa seen through the microscope.

Notes

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1. Nicholas P. Money, *The Amoeba in the Room* (New York: Oxford University Press, 2014.), 89.

2. Money, *The Amoeba in the Room*, 87.

3. Beneficial Bacteria: 12 Ways Microbes Help The Environment - WebEcoist

4. Bernard Dixon. *How Microbes Rule the World* (New York: W.H. Freeman & Company Limited, 1994, XV.

5. Richard Louv, *Last Child in the Woods* (Chapel Hill: Algonquian Books, 2008.), 203.

6. Jeff Lowenfels and Wayne Lewis, *Teaming with Microbes: A Gardener's Guide to the Soil Food Web* (Portland, OR: Timber Press, 2006.), 43.

7. Jeanette Farrell, *Invisible Allies Microbes that Shape Our Lives* (New York: Farrar, Straus, and Giroux, 2005.), 6.

8. Ibid., 8.

9. Ibid., 8.

10. Lowenfels and Lewis, *Teaming with Microbes: A Gardener's Guide to the Soil Food Web*, 52.

11. Ibid., 69.

12. Ibid., 75.

13. Ibid., 85.

14. Ibid., 21.

15. Rifat Hayat et al., "Soil Beneficial Bacteria and Their Role in Plant Growth Promotion: a Review," *Annals of Microbiology Journal*. (Aug 2010): 579, doi: 10.1007/s13213.010.0117.1.

16. Lowenfels and Lewis, *Teaming with Microbes: A Gardener's Guide to the Soil Food Web, 21.*

17. Ibid., 22.

18. Ibid., 25.

19. Ibid., 25.

20. Kristin, Ohlson, *The Soil Will Save Us* (New York: Rodale Press, 2014.), 40.

21. Ibid., 40-41.

22. Ibid., 37.

23. Ibid., 37.

24. Ibid., 34.

25. Ibid., 39.

26. Meredith O'Reilly, "Underground Ecosystem," BeautifulWildlifeGarden.com (2011-2012.) www.beautifulwildlifegarden.com/underground-ecosystem.html

27. Symphony of the Soil, directed by Deborah Koonds Garcia (2012; Mill Valley, CA: Lily Films, 2012, DVD.

28. Ohlson, *The Soil Will Save Us,* 38.

29. Ibid., 107-108.

30. Ibid., 107.

31. Ibid., 108.

Annotated Bibliography

"Beneficial Bacteria: 12 Ways Microbes Help The Environment - WebEcoist." RSS 20. http://webecoist.momtastic.com/2011/09/26/beneficial-bacteria-12-ways microbes-help-the-environment/ (accessed July 23, 2014). I used this website during my earliest stages of research, when I was seeking a direction for my unit.

Dixon, Bernard. *Power unseen: how microbes rule the world*. Oxford: W.H. Freeman, 1994. I used this book for some supplementary facts and only read small portions of it.

Louv, Richard. *Last child in the woods: saving our children from nature-deficit disorder*. Chapel Hill, NC: Algonquin Books of Chapel Hill, 2005. A terrific book to inspire parents and teachers to get the children outside to play, explore, and learn.

Lowenfels, Jeff, and Wayne Lewis. *Teaming with microbes: a gardener's guide to the soil food web*. Portland, OR: Timber Press, 2006. The most beneficial resource for my curriculum unit. This book really set me on the right path.

Money, Nicholas P.. *The amoeba in the room: lives of the microbes*. New York: Oxford University Press, 2014.This book provides a broader view of microbes, but chapter 3 and 8 were more closely aligned to my curriculum unit.

Ohlson, Kristin. *The soil will save us!: how scientists, farmers, and foodies are healing the soil to save the planet*. New York: Rodale Inc, 2014. This book was very enlightening. I recommend reading Teaming with Microbes first for greater comprehension.

Symphony of the soil. DVD. Directed by Deborah Koons Garcia. Mill Valley: Lily Films, 2012. A powerful film that truly explains the importance of the soil food web and the impact it has on Earth.

Resources for Students and Teachers

http://www.kidsbiology.com/biology_basics/index.php As the name suggests, this site offers information for kids about biology.

www.**youtube**.com/watch?v=J5rGo3uBFIU The video shows how to construct a Berlese Funnel using a two-liter soda bottle.

http://urbanext.illinois.edu/soil/ This website is perfect for upper elementary students. It is kid friendly, but contains a wealth of information about the soil.

http://www.dirtdoctor.co.nz/uploaded/file/Advanced%20Soil%20Biology%20Handout.pdf This website has great images. The text is more appropriate as a teacher resource.

http://www.nrcs.usda.gov/wps/portal/nrcs/photogallery/soils/health/biology/gallery/?cid=1788&position=Promo This website is awesome. It has wonderful pictures and information that corresponds to this curriculum unit.

http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/edu/college/?cid=nrcs142p2_054312 This site offers a list of powerful quotations about the soil.

Appendix A: Implementing District Standards

4.4 The student will investigate and understand basic plant anatomy and life processes. Key concepts include

a. the structures of typical plants (leaves, stems, roots, and flowers);
b. processes and structures involved with reproduction (pollination, stamen, pistil, sepal, embryo, spore, and seed);
c. photosynthesis (sunlight, chlorophyll, water, carbon dioxide, oxygen, and sugar); and
d. dormancy.

Plants are an integral part of the soil food web. The structures of the plant and the plant's life processes impact the rhizosphere and the organisms that live in the soil.

4.5 The student will investigate and understand how plants and animals in an ecosystem interact with one another and the nonliving environment. Key concepts include

a. behavioral and structural adaptations;
b. organization of communities;
c. flow of energy through food webs;
d. habitats and niches;
e. life cycles; and
f. influence of human activity on ecosystems.

This standard is the most essential one. The soil food web and the microbes illustrate every facet of this standard.

4.8 The student will investigate and understand important Virginia natural resources. Key concepts include

a. watershed and water resources;
b. animals and plants;
c. minerals, rocks, ores, and energy sources; and
d. forests, soil, and land.

Teaching my students to become stewards of the Earth will help them not only to understand Virginia's important natural resources, but also how to conserve them.