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The Alien in Your Backyard: Using Exoplanetary Science to Explore the Ecosystems of Earth

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Introduction

Years ago, when I was in the third grade, I had the most amazing teacher. Her name was Mrs. Holt. She was firm, but fair, with a ready laugh and a listening ear, and she was a master in building relationships with her students and their families. Through the strength of those relationships, she was able to bring out the very best in each of us in her classroom. In addition to her knack for relationship-building, what I remember most clearly about her classroom is the way in which she did not divide the day into discrete subjects. Luckily, this was in the days before standardized testing! Most of our learning occurred through asking big questions about topics that fascinated us—and then doing the reading, writing, studying the math and the relevant history, and setting up experiments to answer those questions. This integrated approach lit a fire in each of us, and we were better, more focused, and passionate learners because of it. I feel like it is safe to assume that many of us who chose to become educators had a Mrs. Holt somewhere along the line. Perhaps for you, as for me, that teacher continues to inspire you to be like them professionally and to ignite the love of learning in each child under your care.

In elementary school, it is often true that the sciences are, from a curriculum importance standpoint, treated as tertiary at best. This frustrating situation is exacerbated by the standardization of curricula and the advent of high-stakes testing. If it is not directly related to improving that test score, it is all too often treated as disposable! But I believe that the fundamental skills which are taught in the process of scientific inquiry—asking questions one is curious or passionate about, researching and examining the evidence that exists, thinking deeply about the origins of what you read and see, and discovering knowledge and beauty that you never knew were there—are not only fun and fascinating in their own right, but they form the bedrock of all analytical thought. And that is vital to gaining a deep understanding of any subject. My goal in writing this curriculum unit is to do for my students what my third-grade teacher did for me—integrate multiple subject areas in the exploration of big questions, and in so doing, hopefully light a fire in each of them.

I am privileged to serve the students and community of William Fox Elementary School in Richmond, Virginia. Fox is a K-5 urban elementary school with approximately 400 students from diverse backgrounds. Our students come from both socio-economically privileged and disadvantaged homes, in approximately equal measure. There is a significant range of parental involvement and students' home support, which contributes to a wide range in students' skill levels and academic preparedness. Approximately 11% of the population is made up of students with disabilities. All students with disabilities receive at least a portion of their academics in the general education classrooms.

The Alien in Your Backyard: Using Exoplanetary Science to Explore the Ecosystems of Earth is a curriculum unit for upper elementary students focused on using an investigative research approach to study Earth's living things in a variety of aquatic and terrestrial ecosystems by taking on the role of an alien scientist. It will explore the following big questions:

- What is life?
- What is required for life to exist and thrive on Earth?
- How do organisms, communities, and populations of living things adapt to their specific ecosystems?
- What happens when changes to an ecosystem—regardless of their origin—produce fundamental changes to the habitability of that system?

Through these questions, this curriculum unit will delve into multiple Virginia Science Standards of Learning (SOLs), including understanding behavioral and physical adaptations of living things, relationships among living organisms and their dependence on one another for survival, diverse aquatic and terrestrial ecosystems, and the human role in protecting and conserving limited resources. Multiple opportunities for cross-curricular learning in reading, creative writing, and mathematics are also included in the *Activities* section of the unit; teachers are strongly encouraged to implement them too in order to provide a chance for students to engage in integrated, wrap-around learning. However, the *Content Background* section will focus primarily on the science aspects of the unit.

This unit will begin by looking outward—what do we know about life in the universe? Does it exist elsewhere? Could it? How would we know? Using picture books featuring alien characters as an initial jumping-off point, students will learn how astronomers ask and answer these questions, then will cast themselves in the role of a scientist from an alien world. The focus then shifts inward to our own backyard. As part of a research group, they will be tasked by an imagined interstellar body with studying and reporting back on the "newly discovered" planet Earth and its varied ecosystems. The unit culminates in a group presentation utilizing Google Slides.

Rationale

In my thirteen years as an elementary classroom teacher, I have taught grade levels ranging from first grade to fourth. My student teaching was in kindergarten and fifth grade; before that I worked as a preschool teacher for several years. The standards, materials, and pedagogical approaches may be radically different for each age group, but some things have proved to be universal. All students want to be cared about, respected, and, crucially, they want to have fun while they're learning.

Unfortunately, a long tradition of subject-specific teaching, or the breaking up of the school day into defined chunks of instruction, tends to undermine not only the flow of the instructional day, but also that sense of fun. We feel this instinctively, though perhaps more noticeably at the elementary level. Shifting from learning about multiplication to a lesson on nouns to learning about finding the main idea of a fictional text to talking about the states of matter feels rather akin to driving a car with a stick shift and never using the clutch. This situation has been exacerbated by the advent of high-stakes testing, with its ever-increasing emphasis on learning the specific content and skills required to do well on the assessment itself instead of building deep connections among content areas.

The numbers back up our instincts. An annual survey conducted by the Survey Research Center at the University of Michigan's Institute for Social Research in 2005 revealed that, from 1983 to 2005[1] , the number of high school seniors reporting that their coursework was "quite or very interesting" dropped from 34.6 percent to 21.2 percent, while those declaring their coursework to be "very or slightly dull" rose from 19.8 percent to 33.3 percent in the same period. When asked about how often they found their schoolwork to be meaningful, those stating it was "often or always" meaningful dropped from 40.2 percent to 27.5 percent, while those responding that it was "seldom or never" meaningful rose from 18.3 percent to 28.2 percent. Perhaps most distressingly, when asked if they considered school learning to be important later in life, students responding that they believed it to be "quite or very important" dropped from 50.5 percent to 37.1 percent; students answering that school learning would be "not or slightly important" to them later in life rose from 19.9 percent to 28.8 percent.

While correlation is not causation, of course, these are striking data nonetheless. Given how vital it is in our adult lives to be able to effectively synthesize and generalize new information, to find and understand connections across different subject areas, and to be able to apply new information learned, it is deeply counterproductive to train young minds to think of learning as somehow inherently segmented. It simply does not serve students in the long run when we fail to provide opportunities to practice these skills.

My primary purpose in writing this unit is to create such an opportunity. In its execution, this unit integrates language arts, creative writing, computation and problem solving, science, and oral presentation. I believe framing the state-required standards this integrated way will not only be exciting and engaging for the kids, but will also help to show them that education is not about learning disconnected information in set time frames, but rather a process of exploration and connection-making. By integrating standards from across the curriculum I hope to achieve for my students what my own third grade teacher did for me—to spark their curiosity and excitement to go on and explore new things on their own. I hope that they will come away not only with a solid base of scientific knowledge, but with the fundamental understanding of the interconnectedness of learning as a whole.

Content Background

Defining Life: What Is It?

Prior to initiating discussions centered around how living things in various ecosystems interact and meet their basic needs, it is important to come to a common understanding of what life actually is. This is a surprisingly complex question. Most of us would likely define a living thing as an organism with a distinct life cycle: it is born, it grows, it reproduces, it dies. We may go further and note that living things have certain needs like food, water, and shelter or space in which to grow. While useful in its straightforwardness and general applicability, this layman's understanding leaves a bit too much wiggle room. If the goal is to define life as an objective and scientifically researchable term, we must get more specific. For our purposes, we will begin by enumerating the attributes that are common to all life on Earth.

There are eight basic traits that are shared by all living things. They are:

1. Cellular organization: An organism consists of a cell or cells that are bound in an outer protective membrane and displays a high level of organization. Genetic material (either DNA or RNA) is present, either bound in a nucleus—as in the case of eukaryotes—or attached directly to the cellular membrane itself—as in the case of prokaryotes. Organization is present within the cell itself, which is why unicellular organisms such as bacteria qualify.
2. Reproduction: The organism is able to replicate itself, whether through sexual or asexual means.
3. Metabolism: Chemical reactions occur within the organism. This may include the reactions involved in breaking down food, the process of photo or chemosynthesis, or protein construction.
4. Homeostasis: A living organism is capable of maintaining a steady internal state, such as temperature or fluid balance, regardless of the exterior environment.
5. Heredity: The organism passes along its genetic traits during reproduction.
6. Response to stimuli: A living organism demonstrates a reaction to internal or external forces.
7. Growth and development: Living organisms change over time. These changes may be dramatic or subtle.
8. Adaptation through evolution: Often referred to as Darwinian evolution, a living organism is subject to the forces of natural selection. This means that individuals which are best suited for survival in their existing environment have a higher probability of living longer and reproducing.[2]

These traits fit fairly neatly in with our original layman's definition of life. Under closer examination, however, some complications emerge. What about fire? It is certainly capable of growth, it actively must consume material much like we consume food in order to exist, and, it may be argued, fire both reproduces and dies. What about crystals? Or hurricanes? They also grow, replicate, and use energy. Artificial intelligence algorithms and memes also have an ordered structure and arguably demonstrate a form of evolution. Yet few will argue that any of these qualify as living organisms.

Along a similar line, where do viruses fit in? They have an ordered structure, and they certainly grow and reproduce, but only when they exist within a host body. Alone, they are unable to carry out the functions of living things, but when in the proper "ecosystem" are able to replicate and evolve—should this suffice to qualify them as living things?[3]

Conversely, consider the mule! You would likely be hard-pressed to find someone who will argue that a mule is *not* a living thing. However, it is unable to reproduce, and therefore also unable to pass the heredity test or to demonstrate adaptation through evolution. So, as we can see, this seemingly straightforward task—defining what life is—rapidly proves to be anything but. Where to go from here? According to NASA, life is "a self-sustaining chemical system capable of Darwinian evolution."[4] This definition has the benefit of brevity, as it inherently references all eight traits common to life as we know it, while also emphasizing that life is more than just chemical composition. While its focus on Darwinian evolution is overtly Earth-biased—extra-terrestrial life-forms, if they exist, may well operate under a completely different set of genetic rules—it nevertheless captures what we definitively know in a streamlined way. Extraterrestrial life may look and be fundamentally structured completely differently from the life we know, but it would still need to survive within its environment and have the capability of passing on the traits needed to continue surviving in that environment in order to reasonably be considered alive at all.[4]

Ultimately, you will need to choose which working definition is most appropriate for your age group. For the purposes of this unit as written however, we will proceed with the NASA definition as our operational assumption.

Habitability: What is Required for Life to Exist?

The word habitable has a very straightforward definition—a place is habitable if it is suitable or good enough to live in. Organisms can live there. This is also, essentially, a binary definition. A place can either support life or it cannot—there really is no gray area. When we think of a location as being habitable or not, we are, of necessity, thinking about life as we understand it—Earth life. It is, after all, the only actual example we have. Crucially, a planet or other location being habitable does not mean that the location *is* inhabited—only that it has the necessary characteristics which would *allow* it to be inhabited. When working with younger students particularly, this is an important distinction to make. We might even employ a simple analogy: just because a restaurant, by the simple virtue of being a restaurant, could potentially serve pepperoni pizza, that does not mean that pepperoni pizza will definitely be on the menu.

So, what is it that makes the Earth habitable? There is an important distinction to be made even here—the conditions that make Earth habitable for complex plant and animal life are not necessarily the same conditions that make it habitable for every form of life we can find. In taxonomy—the classification of living things—there is an entire category of organisms called extremophiles that are found only in the most extreme environments. They live in and near deep sea hydrothermal vents, where temperatures can reach well over 100 Celsius (212 degrees Fahrenheit). They live in hot springs, in acidic waters, within the digestive tracts of termites and cows, and even in petroleum deposits deep beneath the surface (See Figure 1).[5] Even these extremophiles though, are bound by the necessity of certain planetary conditions

Figure 1. (A) Illustration of a tardigrade from Cosmos. “Tardigrade (Water Bear)” by yourlocal-t-rex is marked with Public Domain Mark 1.0. https://www.flickr.com/photos/155639361@N07/27923522139 (B) Tube worms at a cold seep. NOAA Photo Library. Credit: Image courtesy of Aquapix and Expedition to the Deep Slope, 2007. https://www.flickr.com/photos/51647007@N08/5014886373 (C) Photograph of microbes that have evolved to thrive in boiling acid. “Extremophiles” by Steve Jurveston is licensed under CC by 2.0. https://www.flickr.com/photos/44124348109@N01/4750506867

When astronomers consider the possibility of life on other worlds, they make a distinction between “instantaneous habitability”—the set of conditions at any given place at an instant in time that will support habitability—and “continuous habitability”—the set of conditions in or on a planetary body that can support habitable conditions in at least part of the planetary body over geological time periods.[6] In other words, there is a difference between taking a snapshot of a planetary body and determining whether or not it has the characteristics necessary to be habitable and in considering the totality of factors that go into determining whether or not a planetary body could support life over an extended period of time. A place could be found to have liquid water and sufficient atmosphere to support life as we know it, for example, but at the same time not be of sufficient mass to maintain that atmosphere over a geological time period. For the purposes of this unit, when we talk about habitability, we will be referring to continuous habitability.

What conditions, then, allow for continuous habitability? Earth certainly qualifies as a continuously habitable planet. Life has been around here for 3 and a half billion years or so, after all. Continuous habitability essentially boils down to two main factors: the presence of liquid water and the right temperature.

Water

Life, recall, is a “self-sustaining chemical system.” Life requires chemistry. While it is possible that life forms exist somewhere in the universe with a fundamentally different chemical makeup than here on Earth, there is only one element that is able to form molecules big enough to perform the functions required for life as we know it, and that element is carbon. While silicon is also capable of forming complex molecular chains, those chains are smaller and less versatile than carbon chains. Carbon is a highly versatile atom and is able to bond with a wide range of other elements. The abbreviation CHNOPS is used to denote the six most important elements for life: carbon, hydrogen, nitrogen, oxygen, phosphorous, and sulfur. Together these elements can form a staggering range of organic compounds, and each combination plays a unique role in the creation, maintenance, and continuation of living systems. There are other elements, such as iron and magnesium, which also bond easily with carbon, but the ones mentioned above are responsible for the existence of everything from water to proteins to the nucleic acids DNA and RNA.[7] Water is referred to as the universal solvent because so many substances dissolve easily in it. This allows innumerable other life processes to occur.

Water is, perhaps surprisingly, quite common in the universe. Even just within our own solar system, water is not as scarce as popular imagination makes it out to be. Mars has ice caps, and small lakes of liquid water beneath them. Three of the moons that orbit Jupiter—Europa, Ganymede, and Calisto—are likely to have liquid water oceans flowing below icy crusts. Saturn’s moon Enceladus not only has an ocean, it is also geologically active to the point of shooting jets of salty water hundreds of kilometers out into space![8] Titan, another of Saturn’s moons, not only has an atmosphere, it has liquid methane in such quantities that it has a methane cycle similar to our own water cycle. It is also thought to have a subsurface ocean comprised of ammonia and liquid water. While none of these bodies has liquid water at the surface as we do, nevertheless it remains possible that scientists may one day find evidence of life deep in the oceans of our own galactic backyard. Perhaps they too are teeming with microbial life and odd-looking creatures near their vents—we just don’t know yet.

There is also ample evidence of watery planets elsewhere in the universe. Thousands of planets have been found orbiting other stars in our galaxy alone. Planets that orbit stars other than our own are referred to as exoplanets. Long imagined by science fiction writers, the first true exoplanet was identified in 1995 by European researchers Michel Mayor and Didier Queloz. This Jupiter-sized planet was detected orbiting the star 51 Pegasi, fifty light years from earth. Remarkably, this planet is nearly ten times closer to its sun than Mercury is to ours, with a mere four-day orbit![9]

The processes for detecting exoplanets is fascinating. It is a daunting task indeed to look out across vast interstellar distances and find something as small (in relationship to a star that is) as a planet. It requires an enormous amount of precision, and that level of precision is no mean feat. Author and astrophysicist Adam Frank describes the problem this way:

> The Sun, for example, would appear a trillion times brighter than the Earth when seen from the stars. That means trying to see an earthlike planet across interstellar distances would be like looking from New York City to AT&T Park in San Francisco, where the Giants play, and making out one firefly next to one of the stadium spotlights.[9]

Evidence of exoplanets can come from several sources, nearly all of them indirect. Astrometry, which has not had a lot of success to date, relies on measuring the movement of a star around the center of mass in a star and planet relationship. Essentially, the gravities of the star and the planet act on one another as the planet orbits the star, and scientists infer the presence of a planet by measuring how much the star moves—the star seems to "wobble about the center of mass of the star-planet system."[10] This is very difficult to do because even large planets will have a much smaller gravitational impact on their star than the star will have on them. Simply put, it is just very difficult to measure accurately.

Another detection technique is the use of radial velocities. This technique led to the discovery of the first exoplanet—51 Pegasi b in 1995—and utilizes the scientific tool that is most relevant to our current discussion of the search for liquid water: spectroscopy. Spectroscopy is the study of the absorption and emission of light by matter. It involves the splitting of electromagnetic radiation—a type of energy that takes forms ranging from radio waves to x-rays, and includes visible light—into its specific wavelengths. These wavelengths create a spectrum, like a prism does when it splits visible light into the rainbow. When visible light passes through a prism, it is separated into the rainbow of colors we all know and love. But when we zoom further into this rainbow, dark lines begin to appear at specific wavelengths. These dark lines, called absorption lines, correspond precisely to specific chemical elements. Scientists can then study these spectra to determine the composition and structure of matter at the atomic or molecular level.

When using radial velocities to detect a planet, scientists look at the spectral data with an eye toward identifying the Doppler Effect. The Doppler Effect is the way wavelengths—of sound or light—change in relation to an observer as they or the observer move. With sound, this can be illustrated by the way the sound of a siren changes as it approaches and as it recedes from a listener. As the siren moves closer the sound of the siren is a higher pitch because the motion of the source compresses the wavelength of the sound waves, and a smaller wavelength produces a higher pitched sound. Conversely, as the siren moves away, the motion stretches the sound wave, and longer wavelengths produce a lower pitched sound. With light, as the wavelength gets closer and shorter, the spectrum shifts towards blue; as it gets further away and longer, the spectrum shifts towards red. This is called, respectively, the "blue shift" and the "red shift."[10] Again, this is an indirect method of detection that ultimately rests on the fact that stars' and planets' gravities affect on another. Because a planet is tugging on a star, the star's light spectrum demonstrates a blue shift as it moves towards us, and a red shift as it moves away. Scientists track the velocity of these shifts and how long it takes them to occur. This in turn allows them infer an unseen planet's mass and distance from the star (Figure 2).

On the surface, this measuring of a star's "wobble" seems to be the same method of detection as astrometry. However, astrometry is attempting to measure changes in a star's position on the sky as the star moves around the center of mass of the planetary system, whereas the radial velocity method is measuring the observable changes in the electromagnetic spectrum caused by the star's motion around the center of mass. We currently possess the technological capability for measuring the latter with a high degree of precision and very low margin of error; we do not for the former, yet.

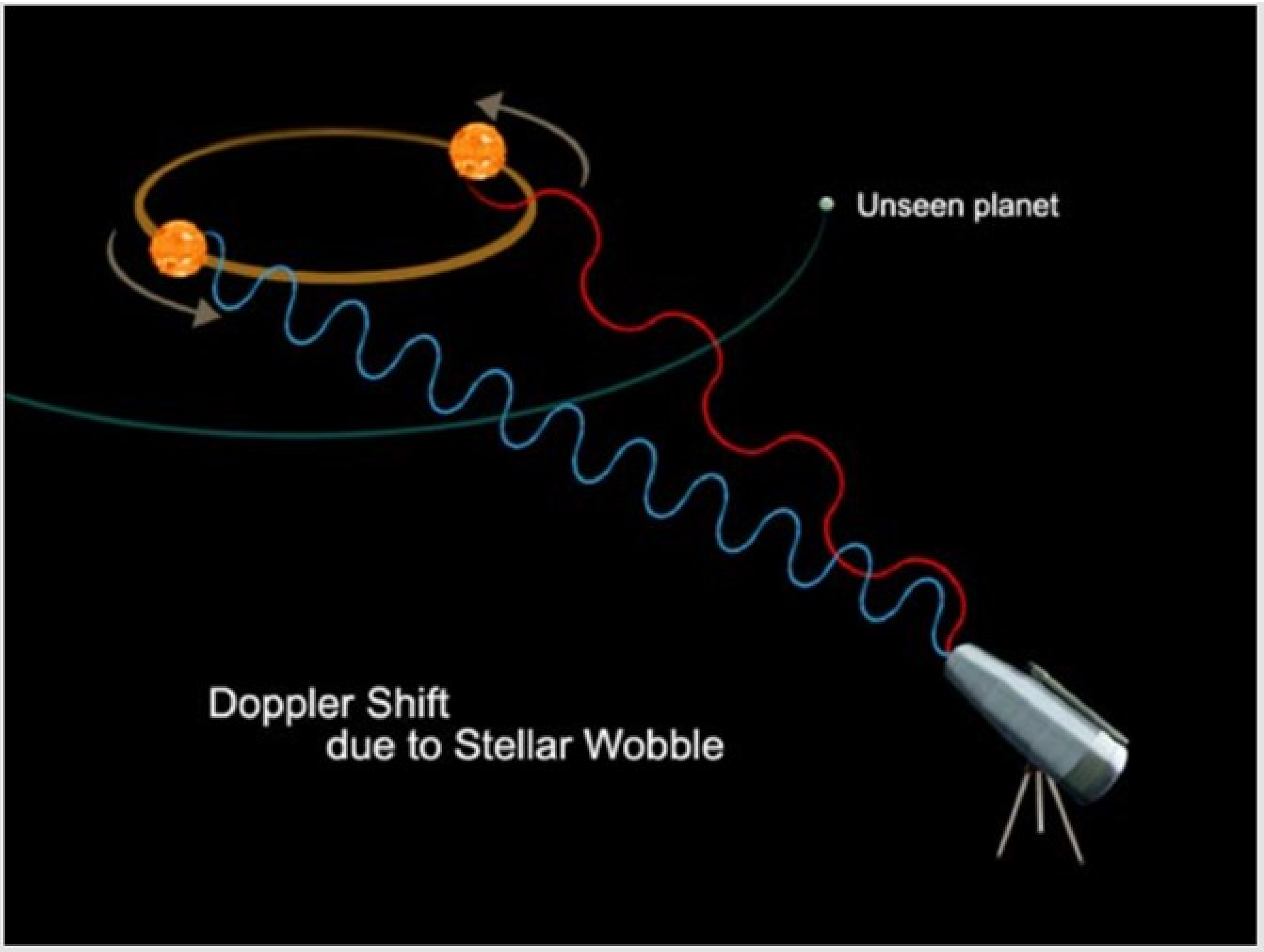

Figure 2. Artist’s illustration of the radial velocity technique for discovering exoplanets. Credit: NASA/JPL-Caltech. https://www.nasa.gov/audience/formedia/telecon-20071106/4.html

A third method of detection is transit photometry, in which scientists measure the total amount of light emanating from a star to infer the presence of a planet. Indeed, this method accounts for the majority of exoplanet identifications. In this case, when a planet comes in front of a star, starlight is blocked and the star appears to dim, as the planet moves away, the start appears to brighten again. Scientists observe and measure this apparent dip in light output, thereby detecting the planet. This method has the added advantage that it can also be used to determine the composition of a planet’s atmosphere. When a planet transits, or passes in front of a star, material in the planet’s atmosphere absorbs a part of the star’s light. By comparing the spectral differences between the unimpeded starlight and the starlight that has passed through the planet’s atmosphere, scientists are able to analyze changes in the absorption lines. This in turn provides the data needed to determine the chemical composition of exoplanetary atmospheres. Analysis of these absorption lines enables scientists to determine the chemical composition of exoplanetary atmospheres. This, in conjunction with other factors, can lead to the conclusion that liquid water is potentially present on a planet’s surface. Figure 3 illustrates this process. By measuring the unimpeded light coming from a star, then measuring the light from the same star as a planet transits in front of it, causing the light to bend through the atmosphere, and then subtracting the one from the other, scientists can determine what changes are due to the atmospheric interference. Next, by further analyzing the absorption lines in the planet’s spectrum alone, they can determine the presence of specific elements and compounds in its atmosphere.[11]

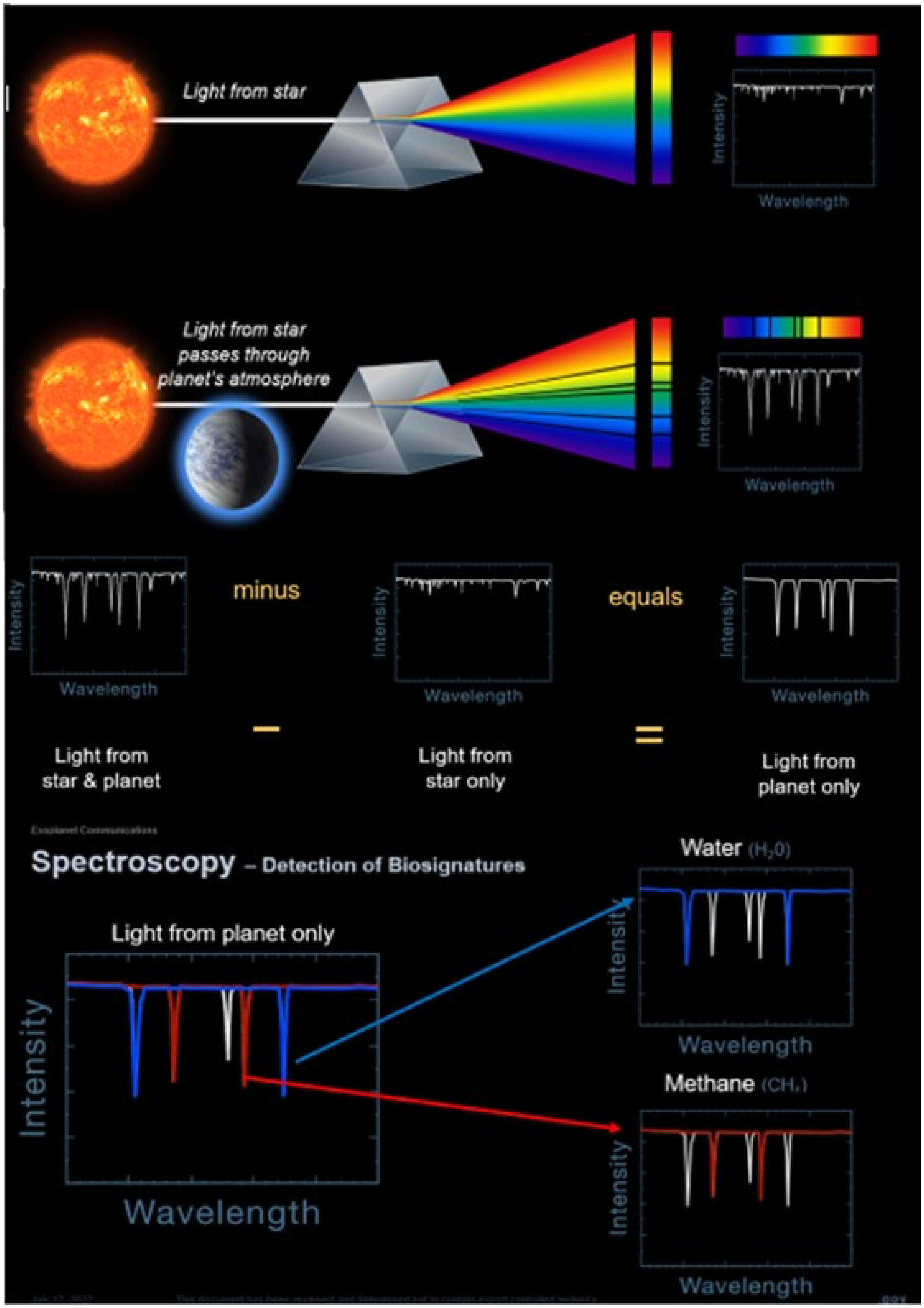

Figure 3. A compilation image created from an animated slide detailing the process of using transit spectroscopy to identify the characteristics of an exoplanet's atmosphere. Credit: NASA/JPL-Caltech. To download the full animated slide, visit https://exoplanets.nasa.gov/resources/2312/spectroscopy-detection-of-biosignatures/

The recently launched James Webb Space Telescope is already captivating the world's imagination with stunningly beautiful and precise images of interstellar bodies. It has also already achieved a major leap forward in precision spectroscopic imaging. In a single 6.4-hour transit, it has captured the distinctive signature of water in the atmosphere of the exoplanet WASP 96-b, a Milky Way gas giant some 1,150 light years away (Figure 4). The potential for this powerful telescope to search for planets that may be habitable is truly remarkable and exciting![12]

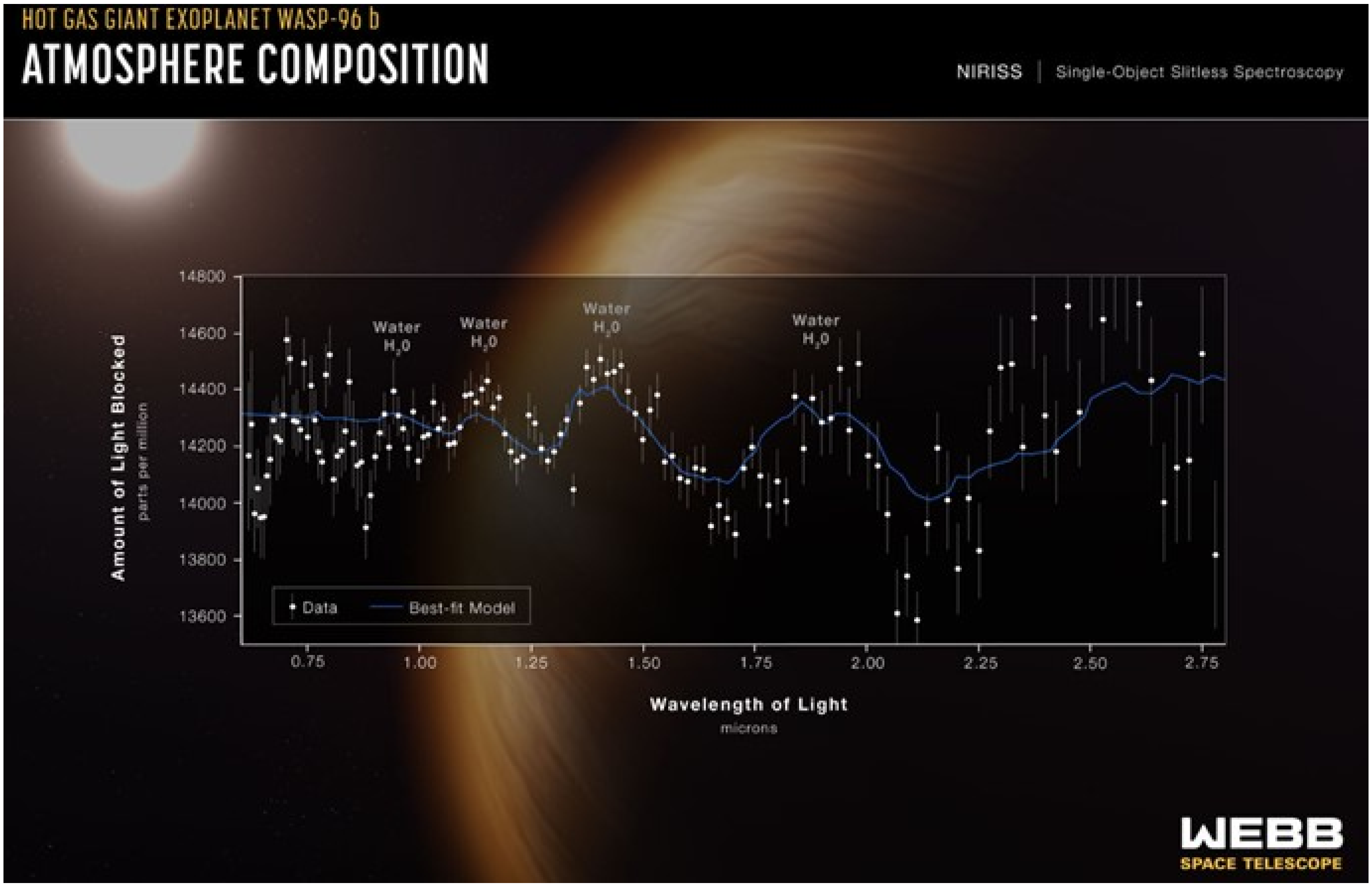

Figure 4. A transmission spectrum made from a single observation using Webb's Near-Infrared Imager and Slitless Spectrograph (NIRISS) reveals atmospheric characteristics—including the presence of liquid water—of the hot gas giant exoplanet WASP-96 b. Credit: NASA, ESA, CSA, and STScI

The presence of water alone, however, is not enough to make a planet continuously habitable. Habitability, and therefore the potential for life to exist, also depends on a planet's temperature.

Temperature and The Goldilocks Zone

For water to serve its function as a biochemical solvent, it must be in its liquid form, and that requires a place that is not too hot, and not too cold. A place that is just right. There are a variety of factors that will impact a planet's overall temperature. From the thickness and composition of the atmosphere, the planet's mass, and its distance from its star, to the planet's geological or tidal activity, and the type of star it orbits—all of these characteristics play a role in a planet's temperature and, therefore, the presence or absence of liquid water. Taken together they impact whether or not a planet is considered to be in a "habitable zone." Habitable zones are also called Goldilocks zones because they represent locations where conditions may be "just right" for life.

Goldilocks zones vary. In general, a planet that is closer to its star would likely be too hot—any liquid water present would simply boil off or vaporize. Yet if that planet's atmosphere is composed of gasses which have a weaker greenhouse effect, or if there is a sufficient quantity of reflective clouds, that close planet could still meet habitability parameters. We would conversely expect a planet that is significantly further away from its star to be too cold—liquid water would simply freeze. However, if that planet's atmosphere has a composition that creates a strong enough greenhouse effect, liquid water could still be present.

This is, in fact, the case for our very own Earth! Without the atmosphere that we have, our average surface temperature would be a mere 255 Kelvin—around minus 18 Celsius or 0 degrees Fahrenheit—far too cold for liquid water. At our distance from the sun we ought to be frozen. Our atmosphere, however, while comprised mostly of nitrogen and oxygen, also contains small amounts greenhouse gases such as carbon dioxide (CO_2) and methane (CH_4), which keeps our average surface temperatures at a much more pleasant 288 Kelvin (15 Celsius, 59 degrees Fahrenheit).[13] This is not at all meant to imply that a greenhouse effect is unequivocally positive. Human activity has been pumping additional gasses with strong heat-trapping properties, like CO_2, into our atmosphere for a couple hundred years now, with well-studied and significant repercussions. The impacts of this activity have ample evidence and not a matter of opinion among serious scientists. Human-driven climate change poses a severe threat to the continuing habitability of our planet, for ourselves at the very least.

We need only glance over at our next-door neighbor Venus to see what a runaway greenhouse effect looks like. Though Venus is similar to Earth in its size, density, mass, and volume, and though its orbit should in principle land it more in our Sun's Goldilocks zone than we ourselves are, the atmosphere of Venus contains such a concentration of CO_2 that surface temperatures are around 480 Celsius (896 degrees Fahrenheit, 753.15 degrees Kelvin). This is clearly too hot for life as we know it.[14]

Habitability on Earth: What is Required for Life to Exist *Here*?

Now that we have spent time looking outward to the stars—defining what life and habitability are, and examining the conditions that would allow an exoplanet or another interstellar body to be considered habitable, we return our gaze to our own backyard. In this section we will delve into the needs of plant and animal life on Earth, how those needs are met in general, and how those needs are met in a variety of specific aquatic and terrestrial ecosystems. In addition to water, all living things need air, energy from food, and the adaptive means to keep itself alive long enough to reproduce.

Food Chains

Living things require energy to live. Metabolism, a trait common to all living things, is the process of converting what a living thing consumes into the energy it needs to carry out its other life processes. A food chain is a model that shows how that energy flows or is transferred from one living thing to another via food in a particular environment. When complex interrelated food chains are shown interacting with each other it is considered a food web. Regardless, these models serve to show that transfer of energy through the ecosystem. Arrows are used to designate the direction that energy is transferred and always point to the organism receiving the energy.

While there are exceptional ecosystems on Earth, such as those where extremophiles thrive, most food chains ultimately begin with the sun. Living organisms in a food chain can be categorized as a producer, a consumer, or a decomposer. Plants use sunlight, air, water, and minerals from the soil to produce their own food through a process known as photosynthesis. Because of this, plants are given the designation of producer in a food chain. Most other living thing—the animals that eat the plants, the animals that eat those animals, the animals that eat both are considered to be consumers. Decomposers are organisms that break down waste or plants and animals that have died. Food chains and food webs do not precisely have a beginning or an end. Instead, the energy flow is part of a continuous cycle that is popularly termed the circle of life.

Physical and Behavioral Adaptations

In order to meet their food needs, and ultimately their reproductive ones, living things must effectively fit in with the particulars of their ecosystem. Biologists refer to this as adaptation. Adaptations are the result of the Darwinian evolutionary process—natural selection—and enhance an organism's probability of survival, including the ability to survive long enough to reproduce.[15] Adaptations are passed down either by inheritance, in the case of physical adaptations, or are taught by adult organisms to their offspring, in the case of behavioral adaptations.

Physical adaptations, sometimes also called structural adaptations, are physical characteristics that help an organism to survive in its environment. Typically, when we think of physical adaptations, we think of animals. The way an animal's body is shaped, its bone structure (or lack thereof), its coloring—all of these are physical adaptations. A physical adaptation is something that is inherent to the organism itself. It is something that it *is*, rather than something that it *does*. There are an enormous number of examples of physical adaptations: a giraffe's long neck, which allows it to eat leaves at the top of the tree, the wide variety of bird beaks and bills designed for everything from cracking nuts to netting fish to drilling holes in trees to get at insects, poisoned skins, hard shells—all of these are physical adaptations. Nor are physical adaptations limited to the animal kingdom! Thorns, leaf shape and size, the color and perfume of flowers, root structures—all of these are physical adaptations as well. In each example, the adaptation in some way contributes to the organism's longevity and likelihood of being able to eventually reproduce.

Two types of physical adaptations warrant special mention, in part because younger students can sometimes confuse them with both behavioral adaptations and with each other. These are mimicry and camouflage. In both cases, an organism's physical appearance aides its survival. The difference lies in the details. Again, these physical adaptations are not limited to animals, but since that is where the confusion for students is likely to occur, that is where we will focus our examples.

With camouflage, an animal's appearance helps to hide it in its environment. This may serve to keep the animal safe from predators, to help a predator hunt or ambush its prey, or both. The animal blends into its surroundings and is difficult to see as a result. Examples include a tiger's stripes, the twig-like body shape of a stick bug, or the rough looking, bark-like color patterns of an owl's feathers. Mimicry is nearly the opposite. In cases of mimicry, the animal definitively does *not* blend into its surroundings. Instead, its physical appearance serves to deceive predators into thinking that an animal is more dangerous than it is, or even simply that it tastes terrible. Large spots on a moth's wings resembling a predator's eyes, bright colors that make harmless tree frogs look like poison dart frogs, or the similarity color bands of nonvenomous and venomous snakes—all of these are examples of mimicry.

Behavioral adaptations are the other side of an organism's adaptive coin. Whereas physical adaptations refer to what organisms *are*, behavioral adaptations are what organisms actively *do*. For example, a turtle's hard shell is a physical adaptation that helps keep it safe from predators. But that physical adaptation only works because of the turtle's *behavior* of pulling its softer, more vulnerable body parts into the safety of the shell when predators approach. Behavioral adaptations also improve an animal's chances of surviving and reproducing. Pufferfish inflating so a predator can’t swallow it, bowerbirds building decorative nests for potential mates, penguins carrying their eggs and chicks on their feet to keep them warm—these are just a few examples of behavioral adaptations. Migration and hibernation also considered behavioral adaptations.

Migration refers to the regular, seasonal, long-range movement of animals from one place to another. This is seasonal event can help animals overcome changes in temperature, precipitation, locating food, and mating. Arctic Terns fly between feeding grounds in the southern hemisphere and breeding grounds in the Arctic Ocean, racking up a remarkable 24,000 miles per annual round trip. Reindeer travel around 3,100 miles annually to find food. Hibernation is the process by which animals, typically in response to reduced access to food and colder temperatures in the winter, slow their metabolic process significantly and go into a deep sleep state called torpor. This allows their bodies to use far less energy, allowing the animal to wait until the environment once again is able to better support their needs.[15] Some types of bears, squirrels, bats, and even some amphibians hibernate.

Ecosystems

Living organisms require energy to survive. That energy is obtained from a variety of sources depending on an organism’s place in a food chain. Within that food chain, living things utilize physical and behavioral adaptations to increase their chances of survival and reproduction. And all of these aspects exist within, and are reliant on, an environment called an ecosystem. It is all connected. An ecosystem, by definition, is “a community of living organisms (plants, animals, and microbes) existing in conjunction with the nonliving components of their environment (air, water, and mineral soil), interacting as a system.”[16] In this section we will briefly review the components of an ecosystem, define some key terms, and then enumerate the specific ecosystems required by the Virginia Science Standards of Learning while providing a brief description of the key characteristics and components of each.

Ecosystems range in size. They can be as tiny as an individual tide pool or as large as the Amazon rainforest. Regardless of its size, an ecosystem is comprised of all the living and nonliving components in a given location that are linked together by the flow of energy through the food web. Living, or biotic, components in an ecosystem are the main actors, so to speak. These are the producers, consumers, and decomposers in a given food web. Nonliving, or abiotic, components however, are also a vital part of an ecosystem. These include things like the amount of light, the temperature, soil composition, precipitation, and more.[16] In many ways, these abiotic components of an ecosystem are ultimately what differentiate them from one another and what determine the ways in which the biotic components of that ecosystem behave and interact.

When we discuss various ecosystems, we employ a lot of vocabulary that can become confusing for young students, but which is important for specificity and accurate understanding. In this context, an organism is simply any one living thing. The word population refers to the entire number of organisms of a specific type. A community encompasses all the populations in an ecosystem, and then an ecosystem adds in the abiotic components to complete the picture. A visual representation of the relationship and flow of this terminology is very useful for younger students (Figure 5).

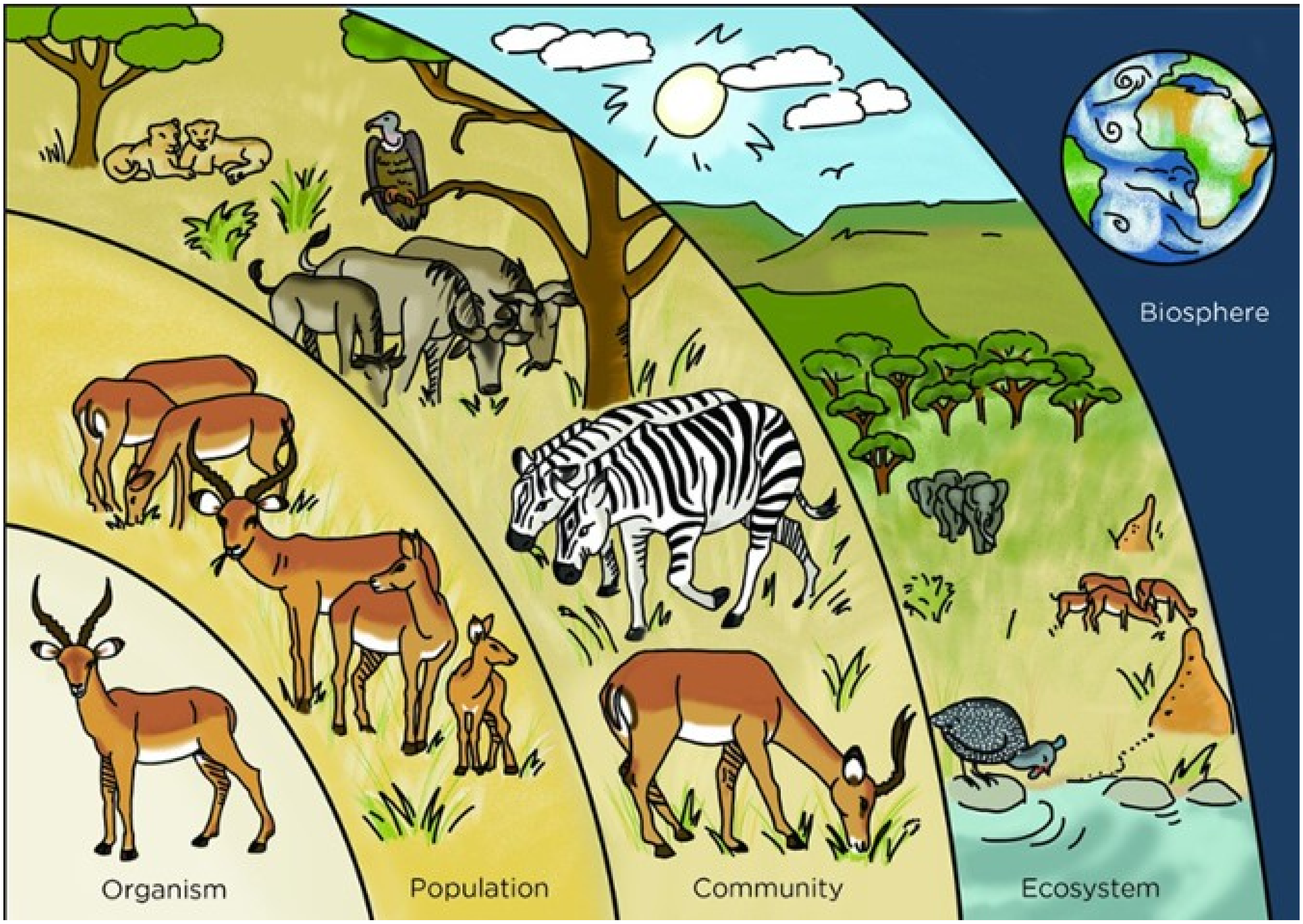

Figure 5. A graphic representation of the levels in an ecosystem. Credit: Siyavula Education. "Ecological levels." Illustration used in Gr 7-9 Natural Sciences (Life and Living strand). https://www.flickr.com/photos/121935927@N06/13578822655

One important hallmark of an ecosystem is that it is fundamentally dynamic. Things happen. At any given time, any given ecosystem is likely to be in the process of recovering from one dynamic event or another. It could be as regular and straightforward as seasonal precipitation changes, as chaotic or sudden as an earthquake, or as relatively slow but seemingly inexorable as climate change. A forest fire, for example, may destroy a section of deciduous forest. This forces the area's life to react in some way, to change their patterns of behavior or to die. But once the flames subside, perhaps the plant life is able to bounce back, or maybe even thrive with the increased access to sunlight created by the older trees burning down. Perhaps the animals were able to run from the fire and then return. The ecosystem is able to recover. This ability to absorb a disruptive event but essentially reorganize or return to a normal state is called ecological resilience.[17]

Any number of external or internal factors can affect an ecosystem's resilience. These factors may be biotic or abiotic. External factors, also known as state factors, refer to things that may influence how an ecosystem operates, but they are not themselves affected by that ecosystem in turn. Examples of external factors influencing an ecosystem might be its climate, the topography, or humans building a factory or strip mall. Internal factors are those factors which are embedded in the ecosystem itself. Examples include the diversity of species present, how much competition there is among species, and the amount of shading created by plant life.[16]

In the Virginia Science SOLs, there are nine ecosystems that are specified as objects of study. They are divided into two categories: aquatic and terrestrial.

- Aquatic:
    - Pond: a shallow body of water surrounded by land that is smaller than a lake. This is typically defined to be less than 12 acres in area, less than 5 meters deep, and with less than 30% emergent vegetation. Ponds may be natural or manmade, and may contain fresh or brackish water.[18]
    - Stream: a small body of moving fresh water. It is differentiated from a river by virtue of its smaller size, and typically feeds into a river system.
    - River: a large body of moving water. The vast majority of rivers are fresh water.
    - Ocean: a large body of salt water that covers 70% of the Earth's surface. Abiotic factors of temperature, depth, and distance from the shore determine the type of plant and animal life are found.
    - Marsh: a type of wetland dominated by grasses, reeds, and other herbaceous vegetation instead of trees. They can often be found at the edges of streams or lakes, forming a transitional role from a terrestrial to an aquatic ecosystem.
    - Swamp: a type of low-lying wetland dominated by woody plants such as trees and shrubs. A swamp may be freshwater, brackish, or saltwater. Like a marsh, a swamp is considered to be a transitional ecosystem. The primary difference between the two is the type of vegetation found there.
- Terrestrial:
    - Desert: an area receiving very little rainfall, less than 10 inches per year. A desert can be hot or cold. The defining characteristic is lack of precipitation, not temperature. The Sahara and Antarctica are both deserts.
    - Grassland: an area with too little rain for tall trees to grow, but too much rain to qualify as a desert. Vegetation is dominated by nearly continuous cover of grasses. A savanna is a type of grassland with scattered individual trees, sometimes called a tropical grassland.
    - Rain Forest: a woodland area with at least 100 inches of rainfall per year. A rainforest is characterized by a continuous tree canopy and rich biodiversity. Rainforests may be tropical or temperate—as with a desert, the defining characteristic is precipitation level, not temperature.
    - Forest: an area dominated by trees.

Ecosystems are diverse and complex. Regardless of an ecosystem's specific and unique characteristics, they are all places where a variety of living organisms exist in intricate and delicate relationships with one another as they strive to meet their life needs. A variety of factors—both natural and human in origin—influence the resilience and sustainability of any ecosystem. By acting as mindful stewards of our natural world, we have the ability to positively impact the environments around us, helping to ensure the circle of life continues to turn.

Strategies

Interactive Notebooks

Interactive notebooks are a tool and a strategy for students to engage with and manipulate information in ways that can include, but go far beyond, traditional notetaking. Using a composition book or spiral-bound notebook, students will create a home for their collected learning. This can include drawings, graphic organizers, foldables, graphs, tables, text excerpts, vocabulary, and more. Under teacher guidance, students add to their interactive notebooks throughout the learning unit. There is a wide range of printable materials and templates readily available with a Google search, which can help reduce the amount of time spent generating materials to go in the notebook. This approach also has the benefit of being easy to differentiate based on student needs and abilities—they can record definitions written on the board or glue in pre-typed definitions and illustrate them, create their own tables or fill in a provided graphic organizer, write their own notes or highlight and annotate pre-printed articles or excerpts.

Anchor Charts

An anchor chart is a way to record and display key information for students to refer to. Importantly, it is not a poster that is mass generated or created ahead of time. Rather, it is created during the lesson and utilized student input. It is intended to capture both students' and teachers' thinking. That said, it is important that an anchor chart be visually appealing and organized in order for students to make use of it. This does not require an enormous amount of artistic skill—just a variety of colorful markers and some chart paper. Creating a framework prior to the lesson is very helpful. Again, this does not need to be overly complex. A simple title and headers for main points will suffice. The key is to fill it in during the lesson, then leave it displayed as long as necessary. When finished, you may even take a picture that students can include in their interactive notebooks. Frequently, once it is time to move on, I laminate completed anchor charts and have them available for students to access and reread during independent reading time or when reading with a partner.

Graphic Organizers

A graphic organizer is a way to visually organize and display related ideas, facts, and/or vocabulary within a learning task. Graphic organizers are particularly useful for brainstorming activities in writing, for categorizing or classifying ideas, for showing cause-and-effect or sequential relationships, and for comparing and contrasting items, ideas, or concepts. As with interactive notebooks, a quick Google search will give you an enormous range of printable, and often customizable, options for free.

Turn-and-Talk

Turn-and-talk is a strategy that increases student engagement by ensuring that all students have a chance to respond to questions and share ideas and understandings. During instruction, the teacher poses a question or provides a short prompt to think about. Students turn to face a predetermined partner and answer, then listen to their partner's response in return. In addition to helping to foster a learning environment in which every child feels that their contributions matter, turn-and-talk has been shown to improve students' expressive language, leading to higher language and ultimately higher text comprehension. It can also improve on-task behavior for students who struggle to attend in the classroom.[19]

Science and Engineering Design Practice

Science aims to answer questions about the natural world by employing a process of observation, research, experimentation and sharing of findings. Engineering seeks to employ existing scientific knowledge and technology to create, design, and spread new devices or technologies to meet the needs of a society. Using both in conjunction with one another allows students to better understand and employ each process.

In the Science and Engineering Design process, students begin by defining a problem or asking a question, brainstorming possible solutions, doing research, planning and building a device or a model to address the problem or answer the question, then test, revise, and, ultimately, share their results. Ideally, students will be given the freedom to develop multiple types of solutions and the time to thoroughly explore the plan-build-test-improve cycle prior to presenting their findings. This may not always be feasible within the time constraints of the average classroom, but teachers are encouraged to at least develop a small bank of presentation options for students to choose from when sharing their research findings.[20]

Activities

Overview

This unit is intended to be taught as a whole piece, with the language arts, mathematics, and science activities being integrated into the entire school day. However, this approach may not be feasible depending on pacing guides, administrative requirements, or prescribed curriculum materials. If that is the case, these activities may be broken up and taught independently. In that event I recommend beginning with the language arts activities and proceeding to the science activities after that. The mathematics activities could be adapted to fit in another time or set aside if strictly necessary. The activities will be broken into three sections, each focused on one subject area, to maximize flexibility. The Procedures portion of each section is subdivided into daily content to be covered, but teachers are encouraged to extend or compress time frames as needed.

Section 1: Language Arts

Objectives

Students will learn to make inferences about fictional texts with a focus on characters and setting, and they will identify specific text and picture clues that support their conclusions. Students will engage in the descriptive writing process, including revision and editing.

Materials

A wide variety of picture books featuring alien characters (see the Materials for Classroom Use section for suggestions), anchor chart materials, projector, drawing supplies

Procedures

- Day 1: Introduce students to the idea of making inferences. A fun way to do this is by showing a Pixar short or a clip from one on YouTube. Watch the video once uninterrupted, then watch it a second time, pausing at key moments to model the process of making inferences about characters, setting, motivations, etc. Emphasize using clues from the video to support the conclusions you come to. Watch a different clip and have students turn and talk to make their own inferences, ensuring that they are identifying the evidence from the clip that supports their conclusion. Create an anchor chart about making inferences.

- Day 2: Review the anchor chart. Choose a picture book with alien characters and read it aloud twice—the first time with fluency and expression, the second time pausing at strategic points to model the process of making inferences and identifying the text and picture clues to support them. After several models, have students make their own inferences by asking questions about the characters and settings.
- Day 3: Repeat the process from day two, placing greater emphasis on having students make the inferences. Use the turn-and-talk process and ensure that students are identifying the text and picture clues that support their inferences. Use this opportunity to introduce the science vocabulary terms included in the Habitability on Earth section of this unit. Begin making inferences about the alien characters' physical and behavioral adaptations, as well as inferences about its home world. For example, if a picture shows an alien that is tall and darkly colored with sharp teeth you may infer that it is a predator, perhaps from a planet with lower gravity, that benefits from its dark shading while hunting.
- Day 4: If teaching in conjunction with the science activities, review the information and anchor chart already created about the planets. Otherwise, initiate a discussion with students about what they already know about the planets in our solar system. Create an anchor to record their knowledge, filling in gaps as needed. Ask students to consider what they might look like on these different planets—what adaptations might they need to have in order to survive in these different environments? How are they making those inferences? Project and watch the video titled "How You'd Look Living on Different Planets" on YouTube (https://youtu.be/GwM4Jg9ChvM) and discuss. Tell students that they will be using what they learn here to help give them ideas for creating their own alien creatures.
- Day 5: Give students material and time to draw an alien creature of their own design. Remind them to think closely about the environment their alien is coming from and to use that to help guide what their alien looks like. Review the anchor chart on making inferences and remind students that their drawings should contain enough detail that a view could make inferences about the alien and its native ecosystem from looking at it. For fun, while students are drawing, consider playing them NASA's data sonification clips from the Hubble Space Telescope images. An explanation of data sonification and the clips can be found at https://www.nasa.gov/content/explore-from-space-to-sound. After students have drawn their aliens, have them take a gallery walk to look at their peers' drawings and make some quiet inferences to themselves. Once everyone has had a chance to see all of the drawings, have them return to their seats and share their alien with a partner. Use the turn-and-talk procedure and have each child make inferences about the other's alien.
- Day 6: In advance, make your own alien drawing. Use the drawing to model making inferences about the creature's adaptations and native ecosystem, then model writing a creative paragraph about the alien. Introduce any remaining science vocabulary and bring it into the paragraph.
- Days 7 – 10: Give students ample to time to write, revise, and edit their paragraphs, working with small groups or individuals as needed. When all students have completed their final drafts, have them share with a partner or the whole class, as time allows. This is also an opportunity to present mini-lessons on using sensory details in writing, sentence structure, adjectives, and more.

Section 2: Science

Objectives

Students will describe the living and nonliving components of terrestrial and aquatic ecosystems and examine the variety of relationships among living organisms in these ecosystems, as well as explore the effects of disruptions to these systems. Students will analyze and describe the adaptations that living organisms use to satisfy their life needs.

Materials

Spiral-bound notebooks or composition books to create interactive journals, projector, computers, a variety of research materials on ecosystems and food chains (see the Materials for Classroom use section for suggestions).

Procedures

- Day 1: Initiate a discussion with students about what they already know about the planets in our solar system. Create a KWL chart for their interactive notebooks and use them to record their knowledge and questions. Project the NASA Space Place website (https://spaceplace.nasa.gov/menu/solar-system/) and use the Solar System tab to explore each planet in succession. You can click on the animated picture of each planet to read interesting facts about them. Have students record at least two facts about each planet in their interactive notebook.
- Day 2: Finish working through the planets on the Space Place website from day one. Review the order of the planets using a mnemonic device or song and create an anchor chart to record this. Include information for use in mathematics activities such as the length of time it takes for light from the sun to reach the planet or the length of its year. This information can be found at the Space Place website, with additional information available by clicking the link to NASA Solar System Exploration—this is an excellent way to scale the unit up by using larger and more precise numbers.
- Day 3: Review the anchor chart and lead a discussion with students about life. Where do we find life in the solar system? How do we know something is alive? Could life exist on other planets? Why or why not? Project and watch the video clip titled “Extremophiles 101” by National Geographic on YouTube (https://youtu.be/MY1d5Saqrc4), then ask students to consider the questions again in light of this information. Discuss that many scientists believe there may be life here in our own solar system, but we do not yet have the technology to prove it. So when we talk about life in the rest of this unit, we are talking about life as we know it on Earth. Have students record that life requires liquid water and the correct temperature to exist.
- Day 4: Explain that scientists have several ways to search for other planets, and many have been found. Project and watch the video clip titled “Searching for Other Planets Like Ours” found on NASA Space Place (https://spaceplace.nasa.gov/exoplanet-snap/en/). If possible, download, shrink, and print the poster on that page for inclusion in the interactive notebook. Discuss the term habitable and relate it to habitat. Have students share what they already know about habitats and guide them to the working definition that a habitat is a place where living organisms are able to meet all of their life needs. Have students record this and draw a picture to go with it.
- Day 5: Review the alien creatures that students drew and explain that for the next part of the unit, they will be pretending to be these alien creatures. Put them into their predetermined groups and introduce them to the fictional intergalactic organization STAR (Society for Terrestrial and Aquatic Research). If this can be done with some fanfare all the better! Tell them that a new planet called Earth has been

discovered, and their teams are being dispatched to learn about its life forms. Project the website Study Jams and watch the video on ecosystems (https://studyjams.scholastic.com/studyjams/jams/science/ecosystems/). Discuss and record key terms, along with illustrations, into the interactive notebook.

- Day 6: Choose one of the ecosystems specified in the Content Background section and model the processes you want students to use when researching their assigned environment. Ideally, have the rubric you plan to use ready to distribute and review to ensure students are clear about the expectations.
- Day 7-10: Give students ample time to research and create their presentations. Regardless of the format you choose to employ, projects must contain:
    - A visual model of the ecosystem featuring key biotic and abiotic components, labeled
    - An explanation (visual or written) of the relationships among the various living organisms and a written projection of what would occur if there were disruptions to that balance
    - An explanation of the physical and behavioral adaptations of at least two different organisms in the ecosystem and an analysis of how those adaptations help the organism to survive

As student groups work, you should continually circulate to provide support and clarification as needed. At the completion of the project, student groups will present their findings to STAR. If possible, invite parents and/or administration to this.

Section 3: Mathematics

This section is more open-ended than the previous two. Because this unit has been written with third grade students in mind, the very large and/or highly precise numbers associated with space are not necessarily appropriate. Additionally, how one chooses to use the numbers—with graphing activities, simple or complex computation, with a focus on place value and rounding, etc.—is highly flexible and can generally be made to fit within whatever pacing parameters a given district employs. Below are a few examples of what I plan to employ in my own classroom, but teachers should not feel limited to these. Due again to the high degree of flexibility with this subject matter, these activities are not linked to a specific day.

Possible Lesson Activities

1. Review the planet anchor chart created during the science portion and pose a series of computation questions based on the recorded information for students to solve on paper or white board. Pair students up to develop their own computation problems for the class to solve.
2. Use the planet anchor chart to develop word problems of varying levels of complexity for students to solve. Put students into small groups to write their own problem, then give individual students sticky notes and employ a gallery walk format for students to solve the problems. These may be collected for use as a formative assessment.
3. Project a scale model of the solar system (there are many visuals available for classroom use with a simple Google search) and simplify the numbers. Alternatively, check out this online scale calculator—input a desired diameter for the sun in inches, and get the distance from the sun to each planet (https://www.exploratorium.edu/ronh/solar_system/)! Even if you don’t attempt to actually measure these distances out, there are lots of ways to play with the numbers and give students a real sense of the immense (to us) scale.
4. When discussing food chains and the impacts of disruptions to an ecosystem, have students calculate what would happen if a population doubled every day for 10 days. How many organisms do you have at

the end of that time? What effects would that have on the ecosystem? This same idea could also be reversed, with the population being halved each day.

5. Discuss the concept of light years—rounding as needed for simplicity) and have students calculate how far light will have traveled over a given period of time.

Appendix on Implementing District Standards

Science Standards of Learning (SOL)

SOLs 3.4 and 3.5 are both focused on living systems and processes. 3.4 focuses on physical and behavioral adaptations, and 3.5 focuses on ecosystems and the relationships that exist among organisms in an ecosystem. SOL 3.4 also specifically incorporates the Science and Engineering Design Practice by requiring students to design and construct a model of a habitat for an animal with a specific adaptation, which will come into the final project and presentation. Similarly, 3.5's requirement to construct and analyze a food chain will also be incorporated into the final project.

SOL 3.8 is focused on Earth resources. This standard will also play into students' final research projects in their discussions of what effects disruptions to their ecosystem would have.

English SOL

SOL 3.2 focuses on oral presentation. Throughout the unit, during all discussions and classroom presentations, students should be encouraged to speak in a clear and organized manner, at an appropriate volume and rate. In the grading rubric for the final presentation, teachers should include expectations for oral presentation.

SOL 3.5 focuses on the reading and comprehension of fictional texts. While instruction in all aspects of fictional text comprehension should always come into play, for this unit teachers should focus on helping students to make connections between reading selections, to identify and compare story elements of characters and settings, and to use evidence from the text—picture or written evidence—to support inferences and generalizations about characters and settings.

SOLs 3.8 and 3.9 focus on the writing and editing process. In this unit students will engage in both creative and informational writing, and should be instructed both in the appropriate techniques for each type of writing and in the process of editing a complete piece of writing for appropriate spelling, capitalization, and punctuation.

Mathematics SOL

SOLs 3.3 and 3.4 both focus on computation, estimation, and practical problem solving. 3.3 emphasizes addition and subtraction of up to 4-digit numbers, while 3.4 revolves around multiplication and division through 10x10. There is a lot of room for flexibility in incorporating these standards into the unit, and the possibilities enumerated in the Activities section above are not meant to be comprehensive. Teachers are encouraged to build upon and adapt those suggestions as desired.

Resources

Annotated Bibliography

NASA. NASA. Accessed July 25, 2022. https://www.nasa.gov/. This site is a treasure trove of resources. There are multiple galleries of open source images, videos, and gifs to enhance instructional presentations, download for use in interactive notebooks, and more. The NASA Audiences tab at the top is of particular use, allowing educators to search by grade level range to find lesson plans, STEM activities, coloring pages, puzzles, videos, and interactive games. This is one to bookmark and keep.

"Exoplanet Travel Bureau." NASA. NASA, July 5, 2022. https://exoplanets.nasa.gov/alien-worlds/exoplanet-travel-bureau/?cid=0%2Ctravel_bureau. This is an excellent source of information on exoplanets, and is of particular note for its artistic emphasis. The links look like old movie posters, and each will provide you with information about the artist's process of using hard scientific data to create their visuals. This is a great resource for teachers and students alike.

"Home – NASA Solar System Exploration." NASA. NASA, July 13, 2022. https://solarsystem.nasa.gov/. This is a wonderful source if you are looking to keep your focus in our stellar backyard.

Frank, Adam. *Light of the Stars: Alien Worlds and the Fate of the Earth*. New York: W.W. Norton & Company, 2019, 144, 137-8. This book is an engaging narrative history of exoplanetary science and how that history should influence our understanding of our place in the universe and here on Earth. If you are looking to scale this unit up for older students, this book can easily be broken into chapters or smaller excerpts.

Fraknoi, Andrew, Sidney Wolff, and David Morrison. "Astronomy." OpenStax: Free textbooks online with no catch, 2016. https://openstax.org/details/books/astronomy. OpenStax is a superb resource. Textbooks for all subject areas are available for free. The Astronomy text provides detailed but highly accessible background knowledge for the teacher who did not necessarily specialize in astrophysics. The Biology 2e text was also utilized in the writing of this unit.

Taylor, Marianne. *The Story of Life in 10 1/2 Species*. Cambridge, MA: The MIT Press, 2020, 48. The premise of this book, taken from the cover image, is "If an alien visitor were to collect ten souvenir life forms to represent life on Earth, which would they be?" Though this is a book primarily about taxonomy, it is packed with wonderful images, diagrams, and flowcharts that could be useful in classroom research and instruction. If you are seeking to scale this unit up for higher grade levels, this is a very good place to start.

Hand, Kevin. *Alien Oceans: The Search for Life in the Depths of Space*. S.l.: Princeton University Press, 2021, 10, 96-101. Particularly good if you want to keep the search for water and life within our solar system. This book draws excellent parallels between the extremophiles we find here on Earth around deep-sea vents and the types of life we could potentially find elsewhere in the solar system. It's a very accessible read and a good potential source for excerpts if you want to scale the unit up for older students.

Materials for Classroom Use

The materials listed in this section are not intended to be comprehensive. Teachers are encouraged to expand on these suggestions.

Books

- These books are intended for use with the Language Arts activities.
    - Even Aliens Need Snacks by Matthew McElligott
    - Aliens Love Astronauts by Melinda Kinsman
    - Babaroo the Alien and the Magic of Healthy Food by Kate Melton
    - Eeek! The Runaway Alien by Karen Inglis
    - Alien Next Door by Joey Spiotto
    - Baloney (Henry P.) by Jon Scieszka and Lane Smith
    - Aliens Love Underpants by Claire Freedman and Ben Cort
    - Your Alien by Tammy Sauer
    - Wuffles by David Wiesner—this is a wordless book and an excellent resource for differentiating instruction for students who struggle with the creative writing activity. You may give them several pages to work with and ask them to just fill in dialogue for the aliens, then from there guide them to think about why those characters would use those words and what that tells the reader about them.
    - The Black Cloud by Fred Hoyle, The Draco Tavern by Larry Niven—both books would be great if you are scaling this unit up for older students. Niven's descriptions of his aliens in this collection of short stories are particularly useful.
- These books may be used with the Science activities.
    - Is There Life in Outer Space? by Franklyn M. Branley
    - Alien Worlds: Your Guide to Extraterrestrial Life by David A. Aguilar
    - What Are Food Chains and Webs, How do Animals Adapt—both by Bobbie Kalman and Niki Walker

Research Websites

- https://spaceplace.nasa.gov/menu/earth/
- https://www.ducksters.com/science/ecosystems/world_biomes.php
- https://www.ecosystemforkids.com/
- https://study.com/academy/lesson/ecosystems-lesson-for-kids-definition-facts.html
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