Evolution of Plants fieldtrip fact sheet

1. The evolution of plants depends upon the relationships of organisms with their environment.
2. Relationships may be cooperative or competitive.
3. Our local natural history is the product of evolutionary processes that have worked for billions of years.
4. One type of relationship is symbiosis. Lichen for example involves fungus and algae and/or cyanobacteria.
5. Fungus shares nutrients with plants in exchange for food in the form of sugars.
6. Some bacteria convert nitrogen from the air into nutrients that they share with plants.
7. The ancestors of land plants were green algae.
8. Plants inherited the ability to do photosynthesis from their green algae ancestors.
9. Endosymbiosis is where one organism lives inside another.
10. Algae formed when cells captured photosynthetic cyanobacteria. The cyanobacteria evolved into organelles called chloroplasts.
11. Chance mutations in DNA and combinations of parental genes cause diversity in offspring.
12. The environment selects offspring with traits favorable for survival.
13. The transition from a watery environment to land involved many changes in plants which further led to diversity and ability to colonize new land areas.
14. The development of roots, stems and leaves were important steps in plant evolution.
15. Plants developed more sophisticated means of reproducing themselves as they transitioned to land.
16. The co-evolution of plants and animals is the product of competitive and cooperative relationships.

Additional information and copies are available online at www.calpoly.edu/~rfield/Darwin.htm.
Click on the link to the Evolution of Plants document and open it with the password: LOMS
Disclaimer: this work in progress may need revisions prior to classroom use.

Evolution of Plants activity sheet

Select the best word to fill in each blank. Circle each word as you use it.

bacteria carbohydrates chloroplasts plants oxygen

1. ________ are land-based multicellular photosynthetic organisms that evolved from green algae.
2. Photosynthesis combines sunlight, water, and carbon dioxide to form ________________.
3. Photosynthesis in algae and plants occurs in cell structures called __________________.
4. These cell structures evolved from _____________.
5. Photosynthesis by cyanobacteria releases a powerful gas ___________.

symbiosis co-evolution selection evolution fungus algae mutations

6. The mutually beneficial relationship of ________ and ________ in lichen is an example of ____________.
7. Over many generations, competition and cooperation lead to __________ of plants and animals.
8. ___________ are tiny alterations in genes that produce variations in traits among offspring.
9. The variation in the traits of an entire population over many generations is called ___________.
10. Natural _____________ determines which traits survive in a given environment.

spores roots stems seeds wind leaves flowers fruit vascular

11. The evolution of _________ structures enabled plants to thrive on land.
12. These structures evolved into _________, ___________ and __________.
13. Plants that produce ________ use the ____________ to transport their offspring.
14. ___________ attract pollinators with colorful modified leaves and fragrances and reward them with nectar.
15. Animals disperse ___________ that are enclosed in ___________.

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Introduction at the rail overlooking the estuary and Morro Rock

Most of you have been at the estuary before. Today I want to show you things that you have already seen, but I want you to experience them, hopefully, in new ways. **Our subject today is the evolution of plants. The evolution of plants depends upon the relationships of organisms with their environment.** Everything you see depends on things you don't see. It is all about relationships - family relationships and working relationships. Family relationships are genetic. Working relationships develop in communities and include behaviors like cooperation to utilize opportunities and competition for limited resources.

Our local natural history is the product of evolutionary processes that have worked for billions of years. What do we see here? We see a big rock of volcanic origin. We see the sky, perhaps clouds, fog, or sunlight. We see water and mudflats. We see plants and animals. The Sun, atmosphere, water, land, and living organisms have undergone many changes over billions of years. Plants and animals have only been around for roughly 500 million years or so.

Look at the trees you see here. There are several kinds, mostly cypress and eucalyptus. Around the Estuary there are others, such as oaks and willows. Are all trees related to each other? Did all trees descend from a common ancestral tree? No - trees evolved many times from herbaceous or soft green plants that were not at all woody like trees and bushes. It was easy for trees to evolve from non-trees. What is the green stuff on the mudflats? Is it a plant or something else? It is green algae, which does photosynthesis like a plant but it lives in water and all of its ancestors lived in water. Algae are not land plants. They do not have leaves, stems or roots.

There is also eelgrass out there, which is a plant that has adapted to water but whose ancestors lived on land. You may see other kinds of algae, brown algae like the giant kelp and red algae, and golden algae. Algae range in size from single celled microbes to 100 foot tall kelp. They all do photosynthesis. Algae are found in salt water, freshwater, soil, sand, and snow. They are even found living in symbiotic relationships with marine animals in tide pools and coral reefs. Photosynthesis is very important to life on Earth as we shall soon discuss.

Why are green algae important? The ancestors of land plants were green algae that had adapted to freshwater, perhaps upstream from an estuary. How did some descendants of ancient green algae acquire adaptations to land and form complex large organisms like trees? Well there are many evolutionary steps between a single celled green algae and a tall tree. Let's look at dry land again for some answers.

At the rock just outside the Museum entrance

Trees have complex vascular structures to transport water and nutrients to every portion of the plant. The earliest land plants were small and thrived in moist environments like swamps and shallow seas. These early plants were nonvascular, like the moss that you may find on trees today. Mosses form dense mats, group tightly together and can absorb water like a sponge.

The tiny plants growing on the rocks and trees here are not moss or true land plants at all. They are lichens. Do you know what lichens are? Lichen is combinations of individuals from two or three kingdoms.What are the five or six kingdoms of life? - Plants, animals, algae, fungus, and bacteria. All lichens are symbioses between a fungus and something that does photosynthesis. A symbiosis is a partnership between unrelated species. Do you know what a fungus is? It could be a mushroom or it could have other forms. Mostly, you cannot see fungi because they are hidden; they have branching threads that dig deep into the soil. Fungi digest their food before they ingest it, unlike animals that have to ingest and then digest their food. Successful fungi live motionlessly along side their food supply unlike animals that must move around to follow food sources.

A fungus can resist dehydration although it prefers moist environments. The fungus cannot make its own food and it cannot do photosynthesis. It gets its food and energy from others, from living or decomposing organisms. Fungus also can get essential nutrient phosphates by dissolving rocks with acids that it produces and secretes. So they have to have relationships with other things in order to survive.

Like other living things, there is a lot of carbon in fungi. What provides the organic carbon and energy for the fungus? In the lichen, the fungus has an intimate durable relationship with either algae or cyanobacteria or both. It protects its partner and gains food. The partner utilizes sunlight, water, carbon dioxide, and some nutrients from the fungus. If the partner does not do its job, the fungus dissolves the partnership – and the partner!

There are many kinds of lichen on the rocks here. Look closely at the gray and black spots – that is not bird guano – although there is some here naturally. You are looking at crustose lichen which forms a thin flat crust on rocks. Foliose lichen rises slightly above the surface like the foliage on a tree. The large lichen hanging from trees like fruit are fruticose.

There are other plants clinging to the rocks here. This rock face is pretty barren and inhospitable and yet several plants have made there home here. We can say that they are adapted to this harsh environment. We see a Dudlyea which clings to the rock face. It is succulent, which means it stores water in its leaves and can get by with no summer water, only moisture from fog. (Point out a few other plants and the conditions that favor their survival). We will talk later about how the environment shapes evolution.

Start walking towards Windy Cove, stop at the trees along the way

As we walk to the mudflats, watch your step, the trail steep and slippery with debris. If you want to look around for a second, stop first.

As I was saying, lichen lived on land before the first plants. (Point out the foliose lichen hanging from the cypress trees.) The first land plants were simple moss-like organisms that lacked vessels to transport water and nutrients. They were therefore limited in size even in damp environments, but could spread across rocks. Neither lichen nor moss could grow on trees because there were no trees! Can you find any types of fungus in this area other than the ones in the lichen? (Stop while the kids look around).

There are fungi associated with the roots of most plants, but you cannot see them because they are underground. They also have symbiotic relationships with plants and help them acquire soluble phosphates. Unlike fungus, plants cannot secrete acids to decompose rocks that contain phosphates. The extensive network of fibers of a fungus increases the plant's access to nutrients in the soil. Half of the food that the plant transports from its leaves to its roots is shared with its fungal partners.

There is also an extensive collection of bacteria in the soil. What purpose do these bacteria play?

Every organism needs nitrogen. Nutrient nitrogen was widely available in water where life first evolved. Lightning can convert or fix some nitrogen gas into nutrient form. Very few organisms can utilize the abundant nitrogen gas in the atmosphere and oceans. Neither land plants nor algae can fix nitrogen molecules. Some cyanobacteria cells can fix nitrogen from the atmosphere. That is one reason cyanobacteria are so important. Animal waste is rich in nutrient nitrogen, but initially there were no animals. Where do plants get nutrient nitrogen from? Some of these bacteria have symbiotic relationships with plant roots and are enclosed in nodules. Legumes such as peas and beans are a typical example of plants with symbiotic relationships for nitrogen fixation.

The cycle of nutrients has been very important to the life of the earth. Plants convert atmospheric carbon dioxide into carbon rich plant fibers. How do we know there is carbon in plants? If a tree burns, the black stuff that remains is carbon or charcoal. Animals, fungus, and bacteria consume and/or decompose plant fibers. Even the nearly indestructible fibers of cellulose and lignin in trees and woody plants are eventually decomposed by fungus and the carbon is recycled into the atmosphere.

Carbon is released into the atmosphere as carbon dioxide, and nutrient nitrogen and phosphorus are returned to the soil through waste products. For hundreds of millions of years, plant fibers were buried in the soil and formed coal. The buried carbon was removed from the food cycle and the atmosphere until people began burning coal.

On the beach at low tide

Let's look at the trees and the algae from down here. (Have the students pick up algae samples.) How are these trees similar to the algae? How are they different? (Elicit as many responses as possible, don't try to correct.) Let's talk about an important step in plant evolution. For billions of years, cyanobacteria were the predominant photosynthesizers. **Plants inherited the ability to do photosynthesis from their green algae ancestors.** The ancestors of green algae were single celled organisms that engulfed their food like amoebas do. They digested and recycled materials for their own growth while extracting energy from the molecules by aerobic respiration, oxidizing sugars and other organic molecules. They ingested and digested cells of cyanobacteria which were much smaller than they were and easily engulfed by them.

More than a billion years ago, one of these cells engulfed a cyanobacteria but failed to digest it. Perhaps it was not as good at digesting or perhaps the cyanobacteria were unusually resistant or maybe they had grown up together and were friends. It turned out that they formed a symbiotic relationship. The cyanobacteria continued to do photosynthesis and was protected from predators because it was engulfed in a large cell. It shared the food it made which kept its protector happy and alive.

Over many generations this endosymbiotic relationship prospered and evolved. "Endo" means "in" or "inside". Endosymbiosis is a form of symbiosis where one organism lives inside another, in this case inside the actual cell of the larger partner. The cyanobacteria divided and filled its partner with multiple cyanobacteria, each sharing the food they made by photosynthesis. When the partner divided, its offspring inherited photosynthetic partners.

Over time, subsequent generations became more fully interdependent with just the right number of cyanobacteria, not too many, not too few. The cyanobacteria had an easy life and got lazy, giving up many of its independent functions to its partners, even transferring most of its genes. The partner also thrived with this easier lifestyle and gained new powers. Eventually the cyanobacteria atrophied to the point where it was nothing more than an organelle of the partner, a chloroplast whose primary function was and is photosynthesis. Cyanobacteria lived and live in communities where most cells do photosynthesis and tolerate the oxygen waste product and a few cells fix nitrogen in an anaerobic environment. They share resources and everyone is happy and thrives.

Chloroplasts evolved independently several times. The common ancestor of the different types of algae is not algae. Green, red, brown, and golden algae acquired chloroplasts from independent instances of endosymbiosis involving cyanobacteria. In the case of the brown algae, the photosynthetic partner was a small alga that had already acquired chloroplasts.

Snack Time

Inside the Learning Center

Use large pad and easel to review the theme (relationships of organisms with their environment) and the sub themes (photosynthesis) presented already. Now we will talk about the other sub themes (transition to land, the development of roots, stems and leaves and more efficient reproduction).

Siblings have different traits because they inherit different combinations of their parent's genes. Chance mutations of DNA introduce additional variations. Your sisters and brothers do not look exactly like you unless you are identical twins. The diversity of traits acquired genetically by offspring affects their fitness in various environments. When the environment changes or when organisms migrate into new environments, natural selection determines which traits persist in populations.

Chance mutations of DNA enabled some descendants of green algae to evolve into multicellular, differentiated, vascular plants with the ability to form leaves and to form and disperse seeds through the production of flowers and fruits. Let's see how that happened.

Use easel and large paper pad—elicit responses from students

In a watery environment where life originated, why was life fairly easy?

moisture is abundant

water is buoyant so that algae can float near the sunlit surface

temperatures are fairly constant

water provides protection from ultraviolet radiation

reproduction is simple and inefficient – sex cells float and mingle

On land, starting with mosses, why was life more difficult?

water is often scarce

plants need structural support – they can't float in air

temperatures are highly variable

ultraviolet radiation is more intense

egg fertilization is complex

What problems have to be solved?

access to water and nutrients such as phosphates and nitrogen

ability to transport water and nutrients limits height

structural support in air

competition for sunlight

dispersal of spores, pollen, and seeds

protection from harmful UV radiation

The transition onto land and the development of roots, stems, and leaves were important steps in the evolution of plants.

Plants weren't the first photosynthesizers on land. Algal scum formed on the land around 1,200 million years ago. An outer wall resistant to drying must exist for spores and plants to live out of water. Plants came onto the land about 500 million years ago. Once plants produced oxygen in abundance, the content of the atmosphere changed dramatically. With the development of roots, stems and leaves, plants could live almost anywhere on earth as long as they had the traits that fit the environment. Diverse environments naturally selected individuals that were best adapted to survive local conditions. Several examples follow. Which do you think developed first? Last?

Humans have blood vessels to transport fluids, nutrients and waste products. Vascular plants have sturdy stems in which fluids and nutrients are transported. What gets transported from the roots up? What gets transported from the leaves down? Trees have xylem to transport water up and phloem to transport sugars down. What is the mechanism that forces water up through the xylem against gravity? Water molecules tend to cling to each other. They form a steady column and as the tree loses water through the leaves, there is upward pressure on the water column.

The first plants to develop a vascular system were ferns. Tall, heavy trees need more than a thin stem or trunk to support their growth. Competition means you have to be the tallest dude in the forest to capture the available sunlight. Increased height relative to other plants means greater distribution of spores which are blown greater distances if they start higher up. Trees have heart wood or lignin which is old or 'dead' wood. The older the tree, the more heart wood there is and the bigger the diameter and the taller the trunk can grow. Have you ever been up to the redwoods and seen the growth rings on a tree? Bark provides protection for the delicate cambium that encircles tree trunks.

The earliest land plants had no roots, just tendrils which sprawled along or beneath the ground. Roots do not photosynthesize and need a supply of sugars; therefore a vascular system is indispensable to rooted plants. A plant must 'dig deep' if it is not in or near a constant or reliable water supply. What is the purpose of roots? Roots can tunnel down or over to moisture. Roots are not all the same. Shallow roots can capture rain water before other competitors do. Networks of rootlets can capture nutrients directly and interact with bacteria and fungus to access nutrients. A tall tree has a large tap root that goes deep into the soil to find moisture and to anchor the heavy weight of the structure above. Deep and extensive roots can break up rock over time and open up new habitats for colonization by fungi and animals

Leaves came after stems were able to extract enough moisture to support the increased water needs of leaves. Leaves may have started as spiny outgrowths to protect early plants from predation. What is the purpose of leaves? Leaves are solar collectors and they often turn towards the sun as it moves across the sky. Many leaves have developed a waxy coating that protect against moisture loss and ultraviolet rays. Leaves also have pores or stomata on the underside which regulate the intake of carbon dioxide and the release of oxygen.

In moist tropical climates leaves are large and broad. Sunlight and warmth are available all year, so that leaves remain on the trees and photosynthesize all year. At mountain elevations, leaves are smaller or needle shape to protect against water loss. Alternately, leaves may be dropped in cold weather to cope with wind and snow so trees go dormant and photosynthesis ceases seasonally. Also it's less 'costly' to lose leaves during cold or dry weather than to continue using energy to repair them. In the desert, leaves are diminished to the point that they are narrow spines in order to minimize water loss.

Plants also developed more sophisticated means of reproducing themselves once they made the transition to land.

Seeds provide protection to the embryonic plant so that it doesn't dry out. The seed coat is the equivalent of an egg shell. There is nourishment in the seed, equivalent to the yolk of an egg, which provides enough energy until the seedling grows roots deep enough to capture sunlight and reach water. Seeds may remain in unfavorable conditions, such as drought for long periods of time and germinate when sufficient moisture returns.

Non-flowering trees, also called gymnosperms (naked seed) such as cedars, firs, pines and junipers, produce cones. Pollen is produced by male parts of the flower and is dispersed by the wind to the waiting female parts. (This discussion will not include the reproductive life cycle of plants.) The result is fertilization of the egg inside a chamber called an ovule. The pinecone functions as a flower with seeds ready for dispersal by falling to the ground and breaking open or by the arrival of an animal seeking food.

Flowering plants also called angiosperms (covered seed) are the most advanced kinds of plants and evolved more recently, about 200 million years ago. Seeds of angiosperms are fully enclosed in a structure called a carpal. Dormancy arose as a response to a drier climate and seeds could not go dormant if they were not fully enclosed. Dry mountain slopes could now be colonized by seeds requiring seasonal moisture.

Flowering plants are also the result of more efficient pollination and fertilization by the actions of animals. Insects derive a benefit from their labors in the form of edible pollen which is sticky and clings to them as they flit from flower to flower. Birds sip nectar. Have you ever looked at a hummingbird's bill and noticed the similarity in shape between the bill of the bird and the shape of the flower? The bird and the flower probably coevolved at one time. The bird gets his dinner and the plant has its pollen delivered to other plants of the same species. Animals scurry or lumber through plants and carry seeds on their bodies to deposit them elsewhere. They also eat seeds and pass them through their digestive tracts. Then miles away from the food source, the animal deposits the remains of his meal in a new location, complete with its offering of fertilizer.

Did you know that a flower is a modified leaf? In the case of annual plants, once a flower develops, no more leaves will grow on that shoot or branch. The seeds ripen, the flower dies and seeds either drop to the ground to start a new plant, or they blow away in the wind, or some animal gets fed. The plant has done its job. Its life cycle has been completed.

With that, we have done our job here. I would like you to remember that the appearance and behavior of plants and animals are adaptations to daily and seasonal changes in the environment and weather that evolved over millions of years. Over generations, populations of plants evolve by means of natural selection of certain traits as they radiate into new environments or as conditions change. Relationships such as cooperation, competition, reproductive strategies and co-evolution within and between all five living kingdoms, facilitated these changes.