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Big Picture Science

The Science Newsletter for Montessori Teachers of 6-15 yr-olds #17 May

Elementary Darwin

Help students discover the core theme of biology

Biology is based on the concept that there is a history behind each organism and ecosystem. Darwin's writings were instrumental in focusing life science on the mechanism that drives change in species.

"Seen in the light of evolution, biology is, perhaps, intellectually the most satisfying and inspiring science. Without that light it becomes a pile of sundry facts – some of them interesting or curious but making no meaningful picture as a whole." - T. Dobzhansky. From an article entitled "Nothing in Biology Makes Sense Except in Light of Evolution", reprinted in Evolution, edited by Mark Ridley (ISBN 0-19-289287-8).

There are **two parts to evolution** concepts, the factual changes in life throughout time as seen in the fossil record and DNA, and the scientific theories that are used to understand the mechanism behind the changes. Charles Darwin was the first to offer a valid explanation of the driving force for evolution.

Montessori students get an introduction to the changes that have occurred in life on Earth with their second Great Lesson. They learn how life started as simple single-celled organisms and developed over billions of years. They need to have a clear idea of Darwin's postulated mechanism (natural selection) of the change.

The fact that the third Great Lessons focuses on the coming of humans means that the "E" word, evolution, has always been a part of Montessori studies. Unfortunately the idea of evolution still offends many people because they see it as a challenge to their religious beliefs. It can be a very emotional topic and therefore difficult to present to some individuals. Misconceptions of Darwin's ideas add to the problem.

Please be assured that **no biologists** who have seriously studied the topic **doubt that life has changed through time**. Virtually all accept natural selection as the driving mechanism for biological change. The theory of natural selection, like any other advancing theory in science, has not stood still however, and there are several important additions since Darwin's time.

The challenge for elementary and middle schoolteachers is to **present Darwin's ideas and the current extensions to them in a clear manner**, understandable to their students. Like other concepts, this one is best demonstrated to children using an activity that they do. I describe one such activity on page 4.

What about *Homo sapiens*, our favorite species? Humans do not operate under the same rules as the rest of nature. This has been the case since agriculture was invented. Natural selection may not be entirely gone from our lives, but we aren't subjected to the same stresses as organisms in nature. Perhaps this is why we have such an overpopulation problem. ❖

Big Picture Changes

Last February, I attended the NCME national conference, where I gave a presentation entitled "Update on the Kingdoms of Life". (It was taped and offered for sale by NCME.) Elementary teachers there suggested the topic for this newsletter.

Change is inevitable. Big Picture Science Newsletter has a new look since I have a new computer that won't use my old fonts. I am now doing my own printing, which means I can't use 11 X 17 sheets, so the pages are all singles. Hopefully once it is in a binder, it will work the same.

Some things are staying the same, including the subscription price. You will find a renewal form for next year enclosed. Be sure to give me your comments and suggestions for next year's topics.

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Natural selection step by step

The ideas that Darwin presented about how life changes are called the theory of natural selection. His words "Descent with modification" are also used to describe this idea. The first thing to clarify for students is that evolution, the change in biota on the Earth over a long period of time, is a phenomenon. The dictionary defines "phenomenon" as "an observable fact or event" and "a fact or event of scientific interest susceptible of scientific description and explanation". In other words, the fossil record and the timeline of life are real. New fossil finds continue to clarify the details, but the overall picture is well established. Scientists before Darwin knew that life had changed over a period of time, but no one else had presented a workable explanation of the driving force, the mechanism that caused the change. In summary, evolution is the change and is a fact, and natural selection is the cause of the change. (See the section on theories – page 5)

Key Ideas of the Theory of Natural Selection. (These appear below in boldface.)

Organisms have more offspring than survive in a natural ecosystem. Darwin calculated that if all the offspring of a pair of elephants survived and reproduced when they were old enough, after 750 years there would be 19 million elephants just from that one pair. The world, however, is not covered with elephants, or any other single species (except perhaps humans). The **population of a species stays relatively stable** unless there are large changes in the environment, and **it contains many fewer individuals than the maximum possible**.

Students can see this in a more personal way if they pick an animal, research its generation time, and calculate how many offspring a breeding pair would produce in certain time period if all the offspring survived and bred. You will need the following data for this exercise: age at sexual maturity, average size of litter or clutch, number of reproductive events per year, average life span. These data are not easy to find. Check your library for a reference set such as *Grzimek's Encyclopedia of Mammals*. You may wish to make a list of animals for which these facts are available, and have students choose from it. This will help prevent student frustration in looking for data on their favorite, but not well known, animal. (It is amazing that we do not have this data on more animals. There is still room for a lot of work in field biology.) Birds are a bit simpler to use as examples since most are sexually mature at 9 months to a year and many have one clutch per year.

Follow the population of organisms for at least 10 generations. This will likely be about 10 years for many birds, but is much less for small rodents. Make a table that lists the generation time period on the left (1st, 2nd, 3rd generations, etc.) and diagrams parents and the generations of offspring. Have a tally of total animals on the right. Students will quickly see that animals and other organisms can reproduce much faster than they actually do in nature and that there must be limiting factors.

The theoretical growth of the smallest animals, the protists, and the bacteria is even more impressive. Some bacteria can divide every 20 minutes given adequate food and the right temperature. At that rate, a single cell would produce over 2 million offspring in 7 hours. It wouldn't take long to make a huge mass of bacteria if they kept doubling. Imagine how many dandelions there would be if all those seeds grew.

Environmental factors prevent the offspring from reaching maximum numbers. Students can postulate what they think controls the numbers of their example organism. Food is likely to be the major factor. Predation, disease, and limits of shelter or habitat also contribute. For example, the number of nesting sites might limit a bird species. Many climate stresses, such as drought, actually limit food supplies.

Since there are limits to the resources available to a species, Darwin realized that **there must be a struggle for survival among individuals** for the scarce resources. Only a small portion of the offspring of an organism continues to live and reproduce.

Variations within the population of each species allow some individuals to compete better for limiting resources and **to produce more offspring** than others do. Darwin said that the organisms that have the most offspring are the most fit to survive the stresses of the environment. From this comes the phrase "survival of the fittest". Note that Darwinian fitness has nothing to do with physical fitness. An old, weak animal with many offspring is considered to be more fit than a young, strong one that has not bred. The fittest in the Darwinian sense is simply the organism with the most offspring.

The **variations** that Darwin considered and that apply here **must be heritable**. They are **passed from parent to offspring**. Darwin had no way to know how these variations arose and how they were passed on, but we now know about DNA and mutations. See page 5 for more. Variations that are not passed on do not count. Lamark, a scientist who lived and worked prior to Darwin, thought that animals could pass on traits that they had acquired. While he contributed other valid ideas to science, his idea of inheriting acquired characteristics turned out to be false.

Sometimes the variations are easy to see, as in a litter of puppies that have different breeds for parents. The pups can have a wide range of color or size. Other times it is masked, particularly in plants. The variations can be in immune systems or biochemical abilities, as well as visible characteristics. A plant species may be able to make a chemical substance that tastes bad to herbivores or one that allows it to gather iron from poor soils. Some individuals may make larger or smaller amounts of these substances.

Have students consider what variations might be present in their example organisms. A look at the limiting factors may help. An animal that is efficient at storing food as fat reserves may survive temporary food shortages better. (Our ancestors must have had many food shortages to survive. Look how great we are at storing food, especially in middle age. Sigh!) Another might have a slightly better immune system and fight disease more efficiently, or it might run a little faster and evade more predators. An animal with smaller stature might be better at surviving during food shortage, but a larger one might win more mates if food were plentiful. Competition for mates is important and has lead to some astounding animal (the huge antlers of elk) and flower (orchids that look like bees) characteristics.

Over a long period of time, the organisms that are most fit to survive pass on their characteristics to their offspring, and the **species can change** and even **gradually become a new species**.

Darwin in a nutshell:

- Natural selection is the unequal ability of individuals to survive and reproduce.
- Natural selection results from an interaction between the environment and the inherited variations in individuals within a population of organisms.
- Natural selection produces populations of organisms that are adapted to their environment (have characteristics that help them survive and reproduce).

Why aren't organisms perfectly adapted?

When you think about Darwinian fitness and the process of evolution, it is often puzzling that organisms aren't perfectly fit to survive. One very important idea is that **a species doesn't know what stresses it will face in the future**. **Variations**, also called **genetic diversity**, have been described as **nature's library of solutions to life's problems**. When a change occurs in the environment, if there are many variations, odds are that some member of the population will have the genes it needs to survive and reproduce. On a planet with a crust made of moving plates, change is inevitable. It is only when the change is too much too fast and totally overwhelming that species become extinct. The removal of the natural environment to which the organism is adapted is an extreme change. If it happens on a time scale of much less than several thousand years, it is usually devastating to the species. Hence human removal of habitat endangers many species. Asteroid impacts cause even more drastic changes on a large scale.

Variations are continually generated in a population. A species can't simply be great at living in today's precise conditions. Some individuals have to have some reserves – "plan B" – for surviving change. Reserves of variations help some of the population survive in case of climate change, new predators or diseases, or other stresses. In the long run, the generalist organism, which has at least some ability to use many different environmental resources, survives. The specialist organism, which is very well adapted to use the resources of a specific environment, succumbs, but may thrive in the short term if the resources is needs are abudant. Many specialist species, such as the giant panda, are endangered, while humans, the ultimate generalists, cover the planet.

The term "**preadaptation"** means that genetic traits that help an organism survive were already present when the change occurred. The amphibians are thought to have evolved from a group of fishes with lobed fins. The fishes had these heavy fins on their dorsal, as well as, ventral surfaces, so the fins didn't start out as a way to move on solid surfaces. They were a preadaptation was modified into limbs in later lineages.

It is important to remember that **if the environment is stable, natural selection maintains the successful form**. It is only when the population experiences a changing environment that natural selection favors change.

Watch your Language! Correct expression of natural selection is important.

Teachers' choice of words can do a great deal to promote or retard the students' understanding of natural selection. Here are some examples of poor and good wording.

"Fishes needed to be able to get out onto land"
"Some fish developed characteristics that later helped their descendants to move onto land."

"Woodpeckers wanted to eat insects in tree bark, so they developed long beaks and tongues."
"The ancestors of woodpeckers gradually developed long beaks and tongues. Birds with slightly longer beaks and tongues survived and had more offspring because they could reach more insects. Gradually they adapted to eating the insects that live under the bark of trees."

"Fruits turn colors when they are ripe so that animals will see and eat them to spread their seeds."
"Fruits that turn bright colors when they are ripe are easier for animals to see. They are more likely to get eaten by animals and carried to a new site to grow"

A simulation of natural selection

I developed this simulation from an activity on the Internet at <http://www.indiana.edu/~ensiweb/lessons/ns.chips.html>.

Materials:

The "habitat" – ½ -1 yard of a colorful print fabric. The print should have features that are about an inch across.

The "organisms" – "yarn worms" – pieces of yarn about an inch long, in 10 colors, including some that match and some that contrast with the colors of the fabric. It may work best to use 5 colors for younger students. I used 4-ply yarn, and separated it into four thin strands. I found the whole piece of yarn sticks up too high. The "organisms" must lie reasonably flat on the fabric. They can be things other than yarn, as long as they differ from the fabric mainly in color. Other items that may work are paper-punched circles from lightweight plastic or stiff paper.

- Make a key to the colors – tape or glue a sample of each yarn onto a white card and label it with a color name. This will help students tell the difference between similar shades of color.
- Package about 100 pieces of each color yarn in separate, labeled containers. Zip lock plastic bags work well.
- For the starting population, package 100 pieces with 10 of each color and label it "starting population".

A tray or shallow box to hold "eaten" worms.

A data table to record the findings. This needs to have 11 columns, one for row labels on the left and one for each color. The color names go in the top row. On the left, the row labels are: % of starting population (use fractions if this is the math level the students understand), number surviving after first feeding, % of population after first generation. Add four more rows for the number surviving and percent for the second and third feedings and generations.

What you do:

Explain that this is a simulation of natural selection. We have a habitat of cloth. On it lives a population of yarn "worms". They have gradually evolved a number of colors. This is a variation on which natural selection can work. They are "preadapted" – they have variations that may help them if there is a change in their environment. Here the change is the arrival of a new predator, a bird that feeds on worms and has especially good color vision. (Perhaps this bird has had a mutation in its color vision genes that gave it better vision.) We will see what happens to the worm population when the predator eats some of the worms and the others "reproduce".

Two students do this activity. One person is the "worm manager" and the other is the bird. They can trade jobs.

1. Lay the habitat fabric out flat on a table. The "worm manager" takes the package labeled "starting population" and distributes the worms randomly across the habitat. During this time the "bird" turns away or leaves the area and doesn't watch.
2. The bird returns. It glances at the habitat and picks up the first worm it sees. It turns and places the "eaten" worm in the holding tray. It turns back and gets another worm. The worm manager counts until the bird has removed 75 worms from the habitat. The bird should not stare at the habitat, but should turn to it, quickly pick a worm, and turn away.
3. When only 25 worms remain, both students remove the remaining worms, count the number of each color that is left, and record it on the data table in the row "number after first feeding". The worms then "reproduce". The worm manager adds three more worms of the same color for each surviving worm. The first generation is complete. Calculate the percentage of each color in the population. For instance, suppose you started with 10 red worms, which made up 10% of the population (10 out of the starting 100). After the bird has fed, there are 8 red worms left. When these reproduce, there are now 32 red worms, making 32% of the population red at the end of the first generation. The worm manager randomly distributes the worms on the habitat. (The bird doesn't watch.)
4. The bird again removes the first worm it sees and continues until 75 have been removed. Record the number of each color left. The worms reproduce (add three more of each surviving color). Record the percentage of each color left after this second generation. Do the same for the third generation.
5. After the data are recorded, students sort and return the worms to their bags for the next group. They place equal numbers of each color, with a total of 100 in the starting population bag.

Which colors were the **fittest to survive**? Sometimes it is not the colors that you guess from a separate look at the fabric and yarn. If you have a color-blind person available to be the bird, this can give an interesting difference to the data. You can also have the "bird" person wear tinted glasses or hold a colored filter or transparent, colored report cover in front of his/her eyes and compare to data from normal vision. Discuss how **measurable characteristics of the** worm **population changed** because of the selection by the bird. (Emphasize the "measurable" part – a necessity for any scientific study.) What would happen the worms were all the same color at the beginning? Could a predator who could see them clearly wipe them out? Why is **genetic diversity important for the long-term survival** of a population? ❖

Other evolution ideas

The Pattern of Evolution: If you drew a diagram of an ancestor and its descendants, it would not be a linear path (not like a ladder, rising from one rung to the next). Instead, you would have something that looks like a multi-tiered bush. Several species arise from the ancestor, a reflection of the process called adaptive radiation. Some of those species will go extinct and some, in turn, have several descendant branches.

The population is the unit of evolution. Evolution doesn't happen to individuals, except on Star Trek. Since each local population has a unique library of genes, it can endanger the species when populations are lost.

Evolution does not always lead to more complex organisms. The changes are random and they also produce simpler organisms. Examples are the reduced body plans of many parasites. There is a limit to how simple an organism can get and still be living, so there is a barrier to movement in the direction of simplicity. On the other end of things, some organisms have gotten increasingly complex over time. This does not mean that evolution has complexity as a goal, just that the random changes produce some simpler organisms and some that are more complex. The complexity builds as the most complex organisms continue to change in both directions.

Evolution doesn't happen at a steady pace. The paleontologists Niles Eldridge and Stephen J. Gould coined the term "punctuated equilibrium" to describe the long periods of stability punctuated by rapid bursts of change. Elizabeth Vrba, another paleontologist, added the idea that the periods of rapid change follow geologic changes, such as continents breaking apart or joining together.

Whenever there is a mass extinction, and many environmental resources are no longer used, **the surviving species evolve rapidly until all the niches are full**. This happened with the mammals after the dinosaurs became extinct and with the dinosaurs in the Triassic when the therapsids became extinct.

What is a scientific theory?

Theories are the important ideas of science. They are our best descriptions of how the world works. Theories try to explain a phenomenon, a real happening that can be observed and measured. The theory tells what we think causes the phenomenon, and how it works.

Theories start as new ideas that have yet to be extensively tested. In the past, they were often the work of one person. Now, with our improved communications, they are usually the work of many scientists. As the theory is tested through experimentation, it either becomes more accepted, or it is discarded if it doesn't work. Many people have to be able to get the same results when the experiments are done the same way. To be accepted a theory has is explain what we can observe of the phenomenon and predict what will happen under circumstances that involve the phenomenon.

After many scientists have gathered data, the theory may become an accepted theory. Our accepted theories include the cell theory of life and the atomic theory of matter. The theories of gravity and of evolution are considered advancing theories. They explain a great deal about their phenomena, but they do not yet explain and predict everything. Scientists are working to gather more data about both these phenomena. It is highly unlikely that either the theory of gravity or the theory of evolution will be discarded. Instead, they will be refined as new data are acquired.

What are variations?

Darwin had little evidence about how information is passed from parent to offspring. He admitted this was a weak point in his theory. When the work of Gregor Mendel became known to science in the early twentieth century, it provided a key part of the explanation. He found that the information is passed in particles called genes. The information in the genes does not blend in the offspring, but remains distinct and can be passed to the next generation. Evolution was seen to be changes in frequency of genes within a population. Many scientists worked to find the molecular basis for changes in the genes. By 100 years after Darwin published his ideas, we knew that the molecule DNA holds the information of heredity and that chemical changes in the DNA bring about alterations called mutations. These mutations are differences in the DNA base sequences, and therefore produce differences in the proteins the cell makes. They are the cause of variations in a population of organisms. Mutations arise constantly. Only a few prove to be advantageous. Sexual reproduction creates the maximum variety of genes since offspring get an assortment of DNA from two parents.

Resources for studying Darwin and natural selection

Books – Dewey decimal cataloging for evolution – 576.8; prehistoric life – 560; human evolution 599.938

Berra, Tim. 1990. ***Evolution and the Myth of Creationism***. Stanford University Press. ISBN 0-8047-1770-2. A good scholarly explanation of the theory of evolution and modern advances, this is useful whether or not you ever need to differentiate science and religion. MS-adult.

Dingus, Lowell and Luis Chiappe. 1999. ***The Tiniest Giants: Discovering Dinosaur Eggs.*** A Doubleday Book for Young Readers. ISBN 0-385-32642-4. You and your students will enjoy this dramatic account of real science investigation. There is good information about the kinds of information that we use to date fossils. LE-UE

Campbell, Neil A., Jane B. Reece, and Lawrence G. Mitchell. 1999. ***Biology***. Fifth edition. Benjamin Cummings. ISBN 0-8053-3044-5. This college biology textbook has a clear explanation of the history and ideas of natural selection.

Gamlin, Linda. 1993. ***Evolution***. Eyewitness Science series. Dorling Kindersley. ISBN 1-56458-233-7. This book presents a good sequence of ideas and is well-illustrated. LE-MS.

Lauber, Patricia. 1996. ***How Dinosaurs Came to Be***. Simon & Schuster. ISBN 0-689-80531-4. This account of early tetrapod evolution introduces the ancestors of mammals and dinosaurs. If you make a phylogenetic (shows the branching pattern of ancestors and descendants) diagram, it will help you keep the groups separate and show the non-linear nature of evolution. LE-UE

McCutcheon, Marc. 1999. ***The Beast in You: Activities & Questions to Explore Evolution***. Williamson Publishing. ISBN 1-885593-36-8. Children are likely to enjoy this lively and imaginative look at human evolution. LE-UE

McNulty, Faith. 1999. ***How Whales Walked Into the Sea***. Scholastic Press. ISBN 0590898310. This is a well-done account of whale evolution, but it gives a ladder-like view of evolution. Remind students that there were many other branches (other related animals) that are not shown. LE-UE

Silverstein, Alvin, Virginia Silverstein, and Laura S. Nunn. 1998. ***Evolution.*** Science Concepts series. Twenty-first Century Books. ISBN 0-7613-3003-8. An excellent look at many aspects of evolution and its theories. UE-MS.

Stein, Sara. 1986. ***The Evolution Book***. Workman Publishing Co. ISBN 0-89480-927-X. This is jam-packed with good information and includes how genes get assorted during chromosome division (p.43). UE-MS

Whitfield, Philip. 1993. ***From so Simple a Beginning: The Book of Evolution***. Macmillan Publishing Co. ISBN 0-02-627115-X. This extensive work ranges from cell biology to ecosystems. It has a good diagram of evolutionary patterns on p.85. There are many good examples to use in lessons for elementary levels. MS-adult level reading.

Charles Darwin's Life and Work

Gribbin, John and Mary. 1997. ***Darwin in 90 Minutes***. Constable and Co. ISBN 0-09-477050-6. A good summary for adults, it will give you stories to tell to students.

Nardo, Don. 1993. ***Charles Darwin***. Chelsea House Library of Biography. Chelsea House Publishers. ISBN 0-7910-1729-X. A more detailed biography for UE-MS.

Parker, Steve. 1995. ***Charles Darwin and Evolution***. Chelsea House Publishers. ISBN 0-7910-3007-5. A good summary of Darwin's ideas for UE-MS.

Twist, Clint. 1994. ***Charles Darwin: On the Trail of Evolution***. Raintree Steck-Vaughn. ISBN 0-8114-7256-6. This account of Darwin's work brings in the historical context of his life. UE-MS.

Periodical articles – For teacher background and advanced secondary students

Altmann, Stuart A. "The Monkey and The Fig: A Socratic Dialogue on Evolutionary Themes." *American Scientist*, vol. 77, May-June 1989, pp. 256-263. Secondary biology classes will enjoy discussing this article.

Linhart, Yan B. "The teaching of evolution – we need to do better." Bioscience, vol. 47, no. 6, June, 1997. This article critiques college biology texts on their presentation of evolution and provides a thorough definition of evolution.

Internet resources

The position statement of the National Association of Biology Teachers on the teaching of evolution can be found at:
http://www.nabt.org/Evolution.html

National Academy of Science has published a book entitled *Teaching about Evolution and the Nature of Science*. It is available online at:
http://books.nap.edu/html/evolution98/ and at: http://www.nap.edu/readingroom/books/evolution98/

University of California at Berkeley, Museum of Paleontology Evolution Wing presents evolutionary theory and its history.
http://www.ucmp.berkeley.edu/history/evolution.html