On T.R.A.C.K.S.

Teaching Resource Activities and Conservation to Kansas Students

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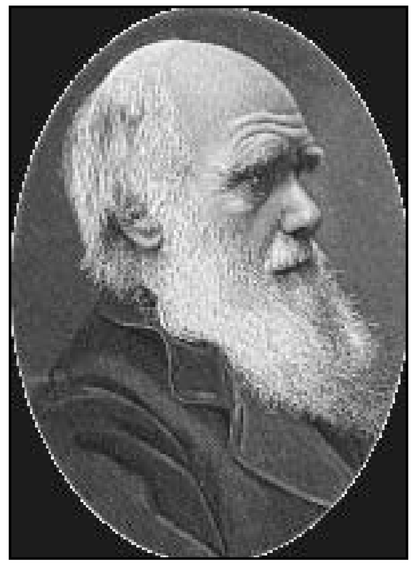
The Scientific Theory of Evolution



INSIDE...

Don't Miss Our Next Issue:

Animal Champions of Kansas

What is the difference between a scientific theory and a belief? That really is the heart of the controversy over the teaching of evolution in biology classes. Our goal for this issue of On TRACKS is to explain what a scientific theory is and how the theory of evolution meets the criteria for a good scientific theory.

WHAT IS A SCIENTIFIC THEORY?

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For most people, a theory is an idea, more or less well thought out, that someone has about a given event or process. In science, however, nothing gets labeled "Theory" until it has undergone a rigorous process of questioning via research from many different approaches and still holds up. Granted, this process isn't perfect because humans aren't perfect, but it does do a good job of helping scientists understand how the world functions.

There are many kinds of science, from astronomy to zoology- with botany, chemistry, and physics in between. But science, worldwide and in all its forms, adheres to a rigid set of standards for experimentation and conclusions, called the "scientific method." Conclusions drawn by scientists who did not follow this method are regularly drawn into question by other scientists, and only those conclusions that have "passed the test" of the scientific method are accepted by the scientific community. So a scientific "theory" is quite different from a "guess" or "hunch." It is an idea that has been tried and tried again, but never disproved (at least not yet!). Cell theory, germ theory, evolution theory, and molecular theory are all so well supported by the facts as we know them, that they have become the cornerstones of modern science for today, but who knows about tomorrow?

It is important to remember that scientific theories are never considered fact and are always open to question and change if new scientific evidence says otherwise.

Public Definition of Theory

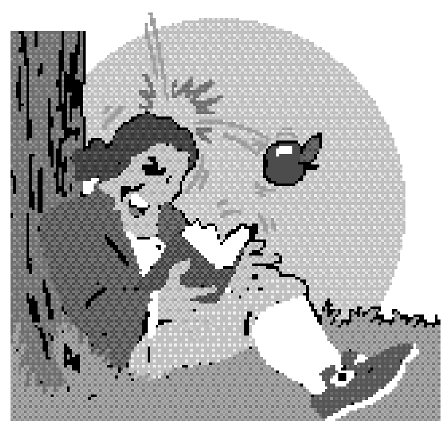
An idea, speculation, or plan as to how something might be done. Most of us have theories about all kinds of things in our lives but these are NOT scientific theories in any sense!

Scientific Hypothesis

An idea or hunch that is used to form an experiment to determine if it is valid. Scientists regularly use an hypothesis to begin a research project.

Scientific Definition of Theory

Overwhelming evidence in support of a general principle explaining the operation of certain phenomena or events that take place in the world as in the Theory of Evolution.



Scientific Law

Implies exact formulation of principles operating in a sequence of events in nature, observed to occur with unvarying uniformity under the same conditions as in the Law of Gravity

The Scientific Method

The scientific method (different from a science methods course) is the process by which scientists, collectively and over time, endeavor to construct an accurate (that is, reliable, consistent and non-arbitrary) representation of the world.

Recognizing that personal and cultural beliefs influence both our perceptions and our interpretations of the natural world, we aim through the use of standard procedures and criteria, to minimize those influences when developing a theory. As a famous scientist once said, "Smart people (like smart lawyers) can come up with very good explanations for mistaken points of view." In summary, the scientific method attempts to minimize the influence of bias or prejudice when testing an hypothesis or a theory.

The scientific method has four steps

1. Observation and description of a phenomenon or group of phenomena.

2. Formulation of an hypothesis to explain the phenomena. In physics, the hypothesis often takes the form of a cause for the phenomena or a mathematical relation.

3. Use of the hypothesis to predict the existence of other phenomena, or to predict quantitatively the results of new observations.

4. Repeat of the experiment by several independent experimenters and properly performed experiments.

If the experiments bear out the hypothesis it may come to be regarded as a theory or even a law of nature. If the experiments do not bear out the hypothesis, it must be rejected or modified. What is key in the description of the scientific method just given is the **predictive power** (the ability to get more out of the theory than you put in) of the hypothesis or theory, as tested by experiment. It is often said in science that theories can never be proved, only disproved. There is always the possibility that a new observation or a new experiment will conflict with a long-standing theory.

Common Mistakes in Applying the Scientific Method

As stated earlier, the scientific method attempts to minimize the influence of the scientist's bias on the outcome of an experiment. That is, when testing an hypothesis or a theory, the scientist may have a preference for one outcome or another, and it is important that this preference not bias the results or their interpretation. The most fundamental error is to mistake the hypothesis for an explanation of a phenomenon, without performing experimental tests. Sometimes "common sense" and "logic" tempt us into believing that no test is needed.

Another common mistake is to ignore or rule out data which do not support the hypothesis. Ideally, the experimenter is open to the possibility that the hypothesis is correct or incorrect. Sometimes, however, a scientist may have a strong belief that the hypothesis is true (or false), or feels internal or external pressure to get a specific result. In that case, there may be a psychological tendency to find "something wrong" with data which do not support the scientist's expectations, while data which do agree with those expectations may not be checked as carefully. The lesson is that all data must be handled in the same way.

Another common mistake arises from the failure to estimate quantitatively systematic errors (and all errors). There are many examples of discoveries which were missed by experimenters whose data contained a new phenomenon, but who explained it away as a flaw in the methodology of the experiment. Conversely, there are many examples of alleged "new discoveries" which later proved to be due to flaws in the methods not accounted for by the "discoverers."

In a field where there is active experimentation and open communication among members of the scientific community, the biases of individuals or groups may cancel out, because experimental tests are repeated by different scientists who may have different biases. In addition, different types of experimental setups have different sources of systematic errors. Over a period spanning a variety of experimental tests (usually at least several years), a consensus develops in the community as to which experimental results have stood the test of time.

Scientific methods are means used by scientific communities for building supportable, evidence-based understandings of our natural world.

Evolution By Natural Selection

The following are excerpts from the article, "Was Darwin Wrong?" by David Quammen found in National Geographic Magazine Online Extra, Nov. 2004. www.magma.nationalgeo - graphic.com/ngm/0411/feature1

Evolution by natural selection, the central concept of the life's work of Charles Darwin, is a theory. It's a theory about the origin of adaptation, complexity, and diversity among Earth's living creatures. If you are skeptical by nature, unfamiliar with the terminology of science, and unaware of the overwhelming evidence, you might even be tempted to say that it's "just" a theory. In the same sense, relativity as described by Albert Einstein is "just" a theory. The notion that Earth orbits around the sun rather than vice versa, offered by Copernicus in 1543, is a theory. Continental drift is a theory. The existence, structure, and dynamics of atoms? Atomic theory. Even electricity is a theoretical construct, involving electrons, which are tiny units of charged mass that no one has ever seen. Each of these theories is an explanation that has been confirmed to such a degree, by observation and experiment, that knowledgeable experts accept it as fact. That's what scientists mean when they talk about a theory: not a dreamy and unreliable speculation, but an explanatory statement that fits the evidence. They embrace such an explanation confidently but provisionally—taking it as their best available view of reality, at least until some severely conflicting data or some better explanation might come along.

Evolution is both a beautiful concept and an important one, more crucial nowadays to human welfare, to medical science, and to our understanding of the world than ever before. It's also deeply persuasive—a theory you can take to the bank. The essential points are slightly more complicated than most people assume, but not so complicated that they can't be comprehended by any attentive person. Furthermore, the supporting evidence is abundant, various, ever increasing, solidly interconnected, and easily available in museums, popular books, textbooks, and a mountainous accumulation of peer-reviewed scientific studies. No one needs to, and no one should, accept evolution merely as a matter of faith.

Two big ideas are at issue: the evolution of all species, and natural selection, as the main mechanism causing that phenomenon

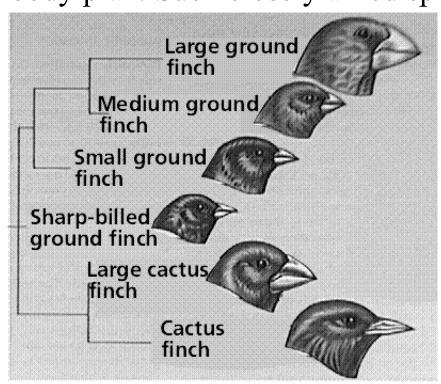
Two big ideas, not just one, are at issue: the evolution of all species, as a historical phenomenon, and natural selection, as the main mechanism causing that phenomenon. The first is a question of what happened. The second is a question of how. The idea that all species are descended from common ancestors had been suggested by other thinkers, including Jean-Baptiste Lamarck, long before Darwin published The Origin of Species in 1859. What made Darwin's book so remarkable when it appeared, and so influential in the long run, was that it offered a rational explanation of how evolution must occur. The same insight came independently to Alfred Russel Wallace, a young naturalist doing fieldwork in the Malay Archipelago during the late 1850s. In historical annals, if not in the popular awareness, Wallace and Darwin share the kudos for having discovered natural selection.

The gist of the concept is that small, random, inheritable differences among individuals result in different chances of survival and reproduction—success for some, death without offspring for others—and that this natural culling leads to significant changes in shape, size, strength, color, biochemistry, and behavior among the descendants. Excess population growth drives the competitive struggle. Because less successful competitors produce fewer surviving offspring, the useless or negative variations tend to disappear, whereas the useful variations tend to be perpetuated and gradually magnified throughout a population.

This describes one part of the evolutionary process, known as anagenesis, during which a single species is transformed. But there's also a second part, known as speciation. Genetic changes sometimes accumulate within an isolated segment of a species, but not throughout the whole, as that isolated population adapts to its local conditions. Gradually it goes its own way, seizing a new ecological niche. At a certain point it becomes irreversibly distinct—that is, so different that its members can't interbreed with the rest. Two species now exist where formerly there was one. Darwin called that splitting-and-specializing phenomenon the "principle of divergence." It was an important part of his theory, explaining the overall diversity of life as well as the adaptation of individual species.

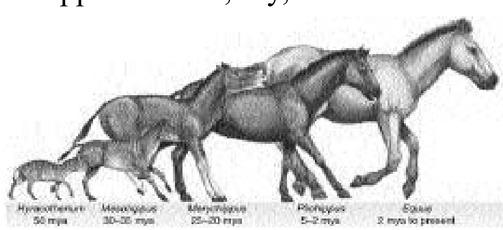
The evidence, as he presented it, mostly fell within four categories: biogeography, paleontology, embryology, and morphology. Biogeography is the study of the geographical distribution of living creatures—that is, which species inhabit which parts of the planet and why. Paleontology investigates extinct life-forms, as revealed in the fossil record. Embryology examines the revealing stages of development (echoing earlier stages of evolutionary history) that embryos pass through before birth or hatching; at a stretch, embryology also concerns the immature forms of animals that metamorphose, such as the larvae of insects. Morphology is the science of anatomical shape and design. Darwin devoted sizable sections of The Origin of Species to these categories.

Biogeography, for instance, offered a great pageant of peculiar facts and patterns. Anyone who considers the biogeographical data, Darwin wrote, must be struck by the mysterious clustering pattern among what he called "closely allied" species—that is, similar creatures sharing roughly the same body plan. Such closely allied species tend to be found on the same continent (several species of zebras in Africa) or within the same group of oceanic islands (dozens of species of honeycreepers in Hawaii, 13 species of Galápagos finch), despite their species-by-species preferences for different habitats, food sources, or conditions of climate. Adjacent areas of South America, Darwin noted, are occupied by two similar species of large, flightless birds (the rheas, *Rhea americana* and *Pterocnemia pennata*), not by ostriches as in Africa or emus as in Australia. South America also has agoutis and viscachas (small rodents) in terrestrial habitats, plus coypus and capybaras in the wetlands, not—as Darwin wrote—hares and rabbits in terrestrial habitats or beavers and muskrats in the wetlands.



Why should "closely allied" species inhabit neighboring patches of habitat? And why should similar habitat on different continents be occupied by species that aren't so closely allied? "We see in these facts some deep organic bond, prevailing throughout space and time," Darwin wrote. "This bond, on my theory, is simply inheritance." Similar species occur nearby in space because they have descended from common ancestors.

Paleontology reveals a similar clustering pattern in the dimension of time. The vertical column of geologic strata, laid down by sedimentary processes over the eons, lightly peppered with fossils, represents a tangible record showing which species lived when. Less ancient layers of rock lie atop more ancient ones (except where geologic forces have tipped or shuffled them), and likewise with the animal and plant fossils that the strata contain. What Darwin noticed about this record is that closely allied species tend to be found adjacent to one another in successive strata. One species endures for millions of years and then makes its last appearance in, say, the middle Eocene epoch; just above, a similar but not identical species replaces it. In North America, for example, a vaguely horselike creature known as Hyracotherium was succeeded by Orohippus, then Epihippus, then Mesohippus, which in turn were succeeded by a variety of horsey American critters. Some of them even galloped across the Bering land bridge into Asia, then onward to Europe and Africa. By five million years ago they had nearly all disappeared, leaving behind Dinohippus, which was succeeded by Equus, the modern genus of horse. Not all these fossil links had been unearthed in Darwin's day, but he captured the essence of the matter anyway. Again, were such sequences just coincidental? No, Darwin argued. Closely allied species succeed one another in time, as well as living nearby in space, because they're related through evolutionary descent.



Evolution of the Horse

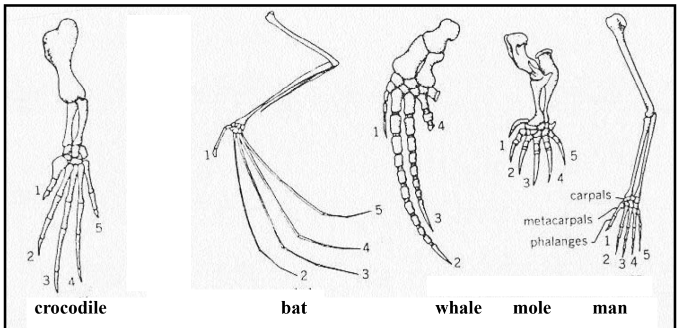
Embryology, too, involved patterns that couldn't be explained by coincidence. Why does the embryo of a mammal pass through stages resembling stages of the embryo of a reptile? Why is one of the larval forms of a barnacle, before metamorphosis, so similar to the larval form of a shrimp? Why do the larvae of moths, flies, and beetles resemble one another more than any of them resemble their respective adults? Because, Darwin wrote, "the embryo is the animal in its less modified state" and that state "reveals the structure of its progenitor."

Morphology, his fourth category of evidence, was the "very soul" of natural history, according to Darwin. All vertebrate animals have backbones. Among vertebrates, birds have feathers, whereas reptiles have scales. Mammals have fur and mammary glands, not feathers or scales. Among mammals, some have pouches in which they nurse their tiny young. Among these species, the marsupials, some have huge rear legs and strong tails by which they go hopping across miles of arid outback; we call them kangaroos. Bring in modern microscopic and molecular evidence, and you can trace the similarities still further back. All plants and fungi, as well as animals, have nuclei within their cells. All living organisms contain DNA and RNA (except some viruses with RNA only), two related forms of information-coding molecules.

Such a pattern of tiered resemblances—groups of similar species nested within broader groupings, and all descending from a single source—isn't naturally present among other collections of items. You won't find anything equivalent if you try to categorize rocks, or musical instruments, or jewelry. Why not? Because rock types and styles of jewelry don't reflect unbroken descent from common ancestors. Biological diversity does. The number of shared characteristics between any one species and another indicates how recently those two species have diverged from a shared lineage.

That insight gave new meaning to the task of taxonomic classification, which had been founded in its modern form back in 1735 by the Swedish naturalist Carolus Linnaeus. Linnaeus showed how species could be systematically classified, according to their shared similarities, but he worked from creationist assumptions that offered no material explanation for the nested pattern he found. In the early and middle 19th century, morphologists such as Georges Cuvier and Étienne Geoffroy Saint-Hilaire in France and Richard Owen in England improved classification with their meticulous studies of internal as well as external anatomies, and tried to make sense of what the ultimate source of these patterned similarities could be. Not even Owen, a contemporary and onetime friend of Darwin's (later in life they had a bitter falling out), took the full step to an evolutionary vision before The Origin of Species was published. Owen made a major contribution, though, by advancing the concept of homologues—that is, superficially different but fundamentally similar versions of a single organ or trait, shared by dissimilar species.

For instance, the five-digit skeletal structure of the vertebrate hand appears not just in humans and apes and raccoons and bears but also, variously modified, in cats and bats and porpoises and



Five-digit skeletal structure of veterbrate hands

lizards and turtles. The paired bones of our lower leg, the tibia and the fibula, are also represented by homologous bones in other mammals and in reptiles, and even in the long-extinct bird-reptile Archaeopteryx. What's the reason behind such varied recurrence of a few basic designs? Darwin, with a nod to Owen's "most interesting work," supplied the answer: common descent, as shaped by natural selection, modifying the inherited basics for different circumstances.

Vestigial characteristics are still another form of morphological evidence, illuminating to contemplate because they show that the living world is full of small, tolerable imperfections. Why do male mammals (including human males) have nipples? Why do some snakes (notably boa constrictors) carry the rudiments of a pelvis and tiny legs buried inside their sleek profiles? Why do certain species of flightless beetle have wings, sealed beneath wing covers that never open? Darwin raised all these questions, and answered them, in The Origin of Species. Vestigial structures stand as remnants of the evolutionary history of a lineage.

Today the same four branches of biological science from which Darwin drew—biogeography, paleontology, embryology, morphology—embrace an ever growing body of supporting data. In addition to those categories we now have others: population genetics, biochemistry, molecular biology, and, most recently, the whiz-bang field of machine-driven genetic sequencing known as genomics. These new forms of knowledge overlap one another seamlessly and intersect with the older forms, strengthening the whole edifice, contributing further to the certainty that Darwin was right.

Among most forms of living creatures, evolution proceeds slowly—too slowly to be observed by a single scientist within a research lifetime. But science functions by inference, not just by direct observation, and the inferential sorts of evidence such as paleontology and biogeography are no less cogent simply because they're indirect. Still, skeptics of evolutionary theory ask: Can we see evolution in action? Can it be observed in the wild? Can it be measured in the laboratory?

The answer is yes. Peter and Rosemary Grant, two British-born researchers who have spent decades where Charles Darwin spent weeks, have captured a glimpse of evolution with their long-term studies of beak size among Galápagos finches. William R. Rice and George W. Salt achieved something similar in their lab, through an experiment involving 35 generations of the fruit fly Drosophila melanogaster. Richard E. Lenski and his colleagues at Michigan State University have done it too, tracking 20,000 generations of evolution in the bacterium Escherichia coli. Such field studies and lab experiments document anagenesis—that is, slow evolutionary change within a single, unsplit lineage. With patience it can be seen, like the movement of a minute hand on a clock.

Species Spotlight: Charles Darwin

Excerpts from the Darwin Exhibit at the American Museum of Natural History www.amnh.org/exhibi - tions/darwin

Happiest at home with his notebooks and his microscope, he shunned the public eye. Controversy made him ill. This brilliant observer of nature kept his most original and revolutionary idea under wraps for decades. Yet today, two centuries after Charles Darwin's birth, nearly everyone knows his name. Who was Charles Darwin?

As a Young Man

Birds' eggs and sea shells, beetles and coins, moths and minerals—as a child, Charles Darwin collected all of these and more. Born in 1809 to a wealthy family in rural England, he spent hours watching birds and lying under the dining-room table, reading. He was an indifferent student, though, and school bored him.

As a teenager, Darwin was thrilled by chemistry, biology, botany and geology. Yet all the while he dutifully pursued the careers his father had selected for him: doctor and then clergyman. As he studied at the University of Cambridge, though, Darwin was singled out by an elite circle of academics who recognized his potential. Finally, his true talent for natural history blossomed.

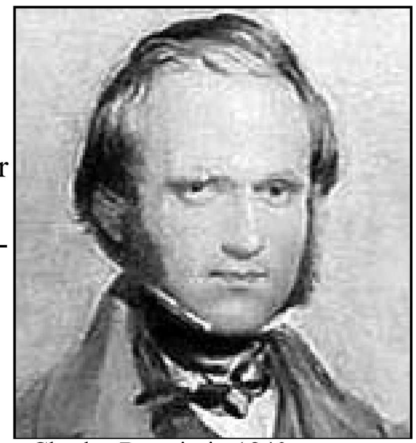
Darwin's mentor at Cambridge, J. S. Henslow, was known for his popular botany lectures and field outings. "It was obvious that Darwin was Henslow's favorite pupil," a fellow student recalled. "Professor Henslow used to say 'What a fellow that Darwin is for asking questions!'" The two became so close that Darwin was known as "the man who walks with Henslow." Henslow profoundly shaped Darwin's thinking about the nature of species.

When Charles Darwin was a student in the 1820s, no science exerted a stronger hold on the popular imagination than geology. The public followed the latest theories and discoveries in amazement. Thousands bought books on the subject, and debates on the history of the Earth and its formation raged among scientists.

By this time, geologists had shown that Earth was not static or fixed—clearly it had undergone sweeping changes over time and was, in fact, still changing. This idea had a huge influence on Darwin's thought. Pondering the long, slow changes in Earth's history would later help shape Darwin's ideas about how plant and animal species, too, had changed over millions of years.

Voyage of the HMS Beagle

In 1831, Charles Darwin received an astounding invitation: to join the HMS Beagle as ship's naturalist for a trip around the world. The captain and crew of the HMS Beagle originally planned to spend two years on their trip. Instead, the voyage took nearly five years, from December 1831 to October 1836. The primary purpose of the trip, sponsored by the British government, was to survey the coastline and chart the harbors of South America, in order to make better maps and protect British interests in the Americas. The position of ship's naturalist, filled by Darwin, was unpaid.


Charles Darwin in 1840

For most of the next five years, the Beagle surveyed the coast of South America, leaving Darwin free to explore the continent and islands, including the Galápagos. In fact, two-thirds of Darwin's time was spent on dry land, largely in the South American wilderness of Brazil, Argentina, Chile and remote areas such as the Galápagos Islands. By any measure, Darwin's labors were hugely successful. He filled dozens of notebooks with careful observations on animals, plants and geology, and brought back specimens of more than 1,500 different species, hundreds of which had never before been seen in Europe.

Darwin later called the Beagle voyage "by far the most important event in my life," saying it "determined my whole career." When he set out, 22-year-old Darwin was a young university graduate, still planning a career as a clergyman. By the time he returned, he was an established naturalist, well-known in London for the astonishing collections he'd sent ahead. He had also grown from a promising observer into a probing theorist. The Beagle voyage would provide Darwin with a lifetime of experiences to ponder—and the seeds of a theory he would work on for the rest of his life.

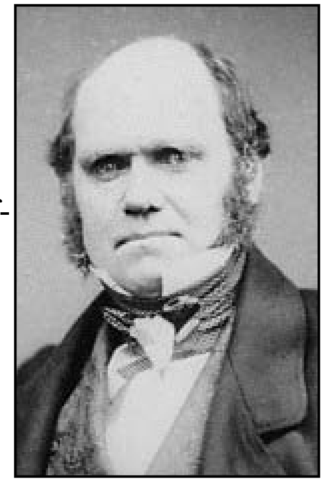
Darwin was something of a scientific celebrity when he got back to England. The strange fossils and unfamiliar animals he had shipped home gained him entry into London's learned circles. Mere months after he left the Beagle, Darwin presented his first paper—on the uplift of the Andes—at the Geological Society.

Determined to earn the respect of the men he called the "great guns," Darwin threw himself into work. Sorting his Beagle specimens and arranging for experts to analyze them were his first priority. What these authorities told him about his specimens—particularly the fossils and the birds—would profoundly affect his developing theories.

Family Man

After a year or so in London, following his return from the HMS Beagle, the 29-year-old Darwin began to think seriously about marrying. But like many an ambitious scientist, he was torn between determination to make a mark and desire to have a family. Would supporting a wife and children mean abandoning his scientific career? A methodical man, Darwin drew up a list of the pros and cons of marriage—and what he called the "nice wife on a sofa" won out. He soon proposed to a woman he had known since childhood, first cousin Emma Wedgwood. Both parties—and both families—agreed it would be the perfect match.

Bonds of real affection linked Emma and Charles throughout their long lives, and they would establish a warm, lively and loving family. Yet two troubling issues surfaced in those early years. Darwin's growing skepticism about religion caused Emma great pain, which in turn caused her husband deep sadness. And Darwin began to suffer increasingly severe and mysterious bouts of illness that would plague his entire working life.



Darwin in 1854, at the age of 43.

Down House

In 1842 Charles Darwin and his family fled London in search of peace and quiet. They found it in a tiny village 16 miles outside the city, and for the next 40 years their home—called Down House—was Darwin's retreat, research station and the hub of his vast scientific network. Working in his study, greenhouse and garden, corresponding with scientists around the world, Darwin patiently completed the puzzle of evolution by natural selection.

As the years passed, the sprawling house at Down filled up with children—the Darwins would have ten in all—and a series of governesses, nurses and pets. Charles and his wife Emma were relaxed and affectionate parents whose children, daughter Henrietta later wrote, felt like "creatures whose opinions and thoughts were important."

Since London days Darwin's health had been fragile. Breaks in the regular routine—even an interesting talk with a visitor—could provoke spells of vomiting and dizziness. But he doggedly pursued his research program, and on some days his work could be an exciting household adventure. Children tracked the flight paths of bumblebees, a governess joined in counting the plant species in a meadow, a longtime servant helped Darwin boil carcasses of small mice and birds to "skeletonise" them for study.

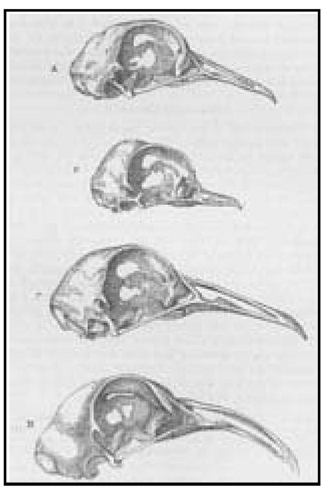
Theory of Natural Selection

All the research Darwin undertook in 40 years at Down revolved around a single grand theme: evolution by natural selection. In at least 16 books and many papers, Darwin explored variation and adaptation. He worked tirelessly to figure out how natural selection had acted on variation to produce the marvelous adaptations he saw.

But in many cases he couldn't do this directly. Extended studies of wild nature—measuring and tracking minute changes in fur, feather or flower over generations—were unimagined by any naturalist of the period. So instead Darwin often turned to domesticated species—manageable and well-documented groups that he, or the experts he knew, could breed and shape. Pigeons, rabbits, cabbages, gooseberries—these would be a major object of study and his window into the workings of selection.

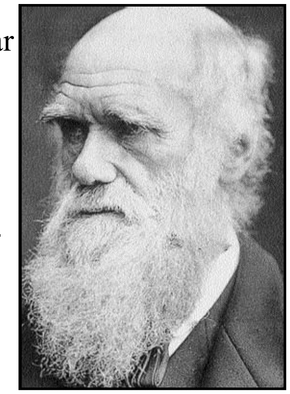
Darwin was trying to find out how much variation existed within a single type of animal in nature. Breeding animals—selecting and perpetuating desired traits—was a sped-up version of the process that gave rise to new species in nature, he thought.

The color, shape and placement of feathers in pigeons are the obvious differences between pigeon breeds, but the skeletons underneath differ, too. Had these skulls belonged to wild birds, Darwin thought, they would be considered different species. And if artificial selection could produce such diversity over decades, what might natural selection produce over millions of years?



Variability in the cabbage family also interested Darwin. The wild cabbage, he knew, had given rise to very different-looking varieties, including Brussels sprouts, broccoli and kale. What accounted for this diversity? "The explanation is obvious," Darwin wrote. Because we humans eat the leaves of these plants, farmers had been selecting the "many useful variations in their leaves and stems" since prehistoric times. Such strong selective pressure produced those distinct shapes.

When Darwin looked at the expressions on people's faces—and at the body language of dogs and cats—he saw evidence for evolution. What Darwin himself observed, and what he learned from scientists studying cultures worldwide, convinced him that all humans have the same feelings. What's more, they show them on their faces in similar ways.



Darwin in the 1870's

Similarly, Darwin thought, animals had recognizable emotions. Chimpanzees could feel disappointment. When they were disappointed, they sulked; and when they sulked, they stuck out their lips like pouting children. Experts of the time believed, wrongly, that we humans had special muscles in our faces so we could express what they called our "exquisite feelings." Darwin's work contradicts this. Our emotions, and the way we express them, connect us with the rest of life on Earth.

Darwin had made observation and studied variations in the natural world beginning with his voyage on the HMS Beagle but for nearly two decades Darwin kept his ideas about natural selection secret. Fully aware that others had been severely punished for such "heretical" ideas, he only confided in his closest friends and continued his research to meet anticipated objections. It took a letter outlining another man's version of natural selection to push him into print. The letter delivered to Down House in June 1858 was sent by the young naturalist Alfred Russel Wallace and it outlined a theory of evolution by natural selection eerily like Darwin's own. Wallace even cited the passage of Malthus (author of *Essay on the Principle of Population* c.1798) that Darwin had cited in his notebook nearly 20 years before. Darwin was distraught: after all the years of work and worry, someone else would get the credit. He hated being scooped—and he hated himself for caring.

Shutting himself in his study, working feverishly, Darwin finally produced the Origin of Species (1859). That book—and its companion volume, the Descent of Man—would spark a revolution. They would also make Darwin the most revered, and controversial, scientist of his time.

Did You Know?

Skandar Keynes (born September 5, 1991 in London) is a young actor best known for starring as Edmund Pevensie in the 2005 film version of The Chronicles of Narnia: The Lion, the Witch and the Wardrobe.

Keynes, who attended the Anna Scher Theatre School from 2000 to 2005, **is the great-great-great grandson of the famous scientist Charles Darwin.** He has an older sister, Soumaya, and his parents are Zelfa Cecil Hourani (who is of Lebanese descent) and Randal Keynes. He studies Tae Kwon Do and plays the coronet and the flute and currently attends the City of London All Boys School along with Daniel Radcliffe (Harry Potter).

Harriet is a Galápagos tortoise believed to be, at an estimated 175 years, the oldest known living animal in the world.

It was originally thought that Harriet was captured by Charles Darwin in 1835 on the Galápagos Islands. DNA testing has in fact indicated her to have been born around 1830. However, the story regarding Darwin is most likely apocryphal. Though Darwin caught three tortoises and took them home to Britain, genetic tests indicate that Harriet belongs to a subspecies endemic to one of the Galapagos Islands that Darwin never visited.

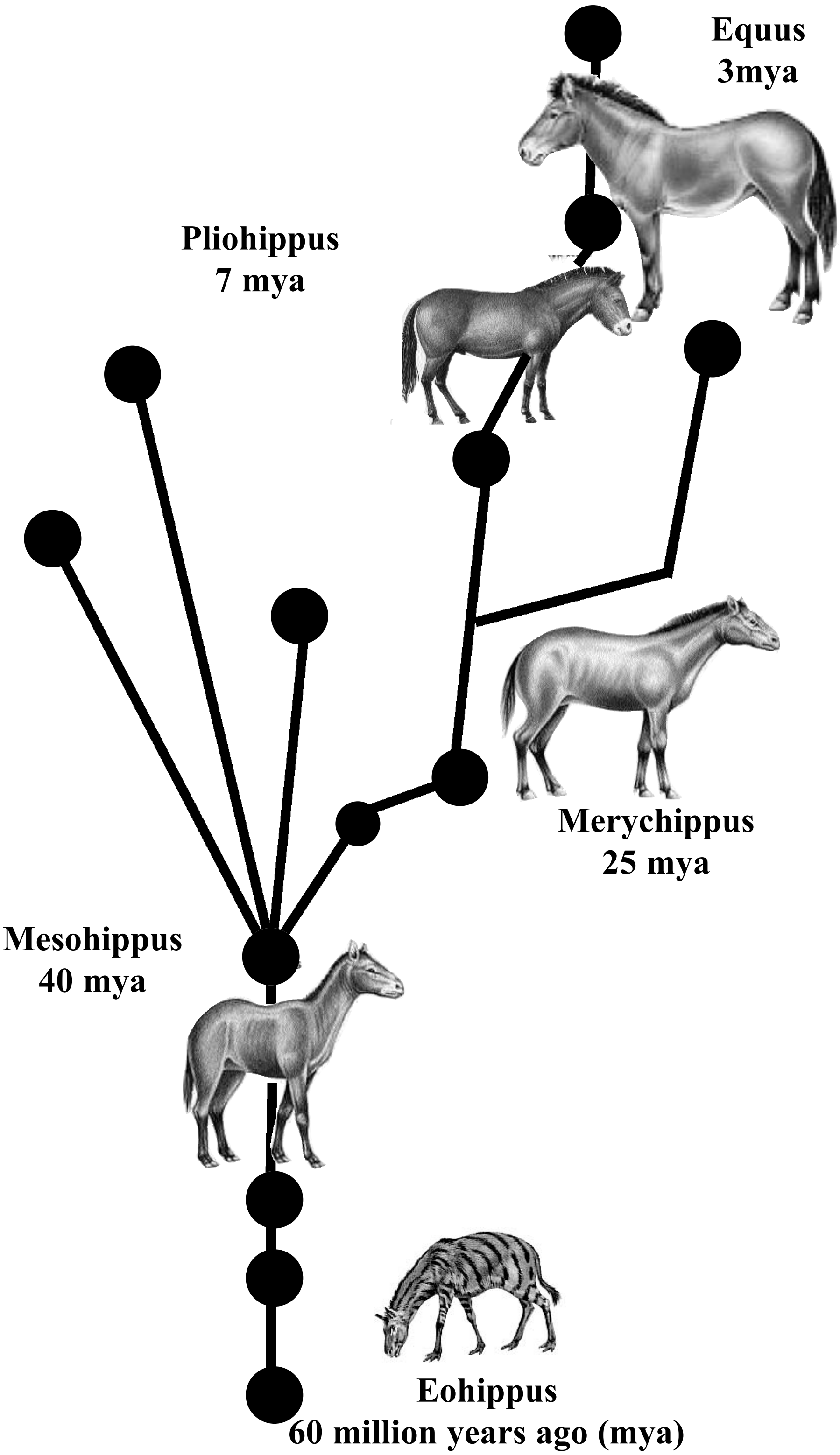
On November 15, 2005, her 175th birthday was celebrated at the Australia Zoo, owned by the Crocodile Hunter's Steve Irwin

sci·ence- the observation, indentification, description, experimental investigation, and theoretical explanation of natural phenomenon. (American Heritage Dictionary)

sci·ence-

1. The act and embodiment of performing the scientific method in order to discover empirically proven truth. (Wikipedia Dictionary)

Evolution of the Modern Horse



Horse evolution is largely recognized as one of the best examples of evolution from the fossil record. Horse species were constantly branching off the "evolutionary tree" and evolving along various unrelated routes. There's no discernible "straight line" of horse evolution. Many horse species were usually present at the same time, with various numbers of toes and adapted to various diets. In other words, horse evolution had no inherent direction. We only have the impression of straight-line evolution because only one genus happens to still be alive, which deceives some people into thinking that that one genus was somehow the "target" of all the evolution. Instead, that one genus is merely the last surviving branch of a once mighty and sprawling "bush."

The Tree of Life

Simply stated, biological evolution is derivation from an ancestor; it is the history of life. It consists of two transformations: **Small-scale evolution** which are changes in gene frequency from one generation to the next and **large scale evolution** which is the descent of different species from a common ancestor over many generations.

Transformation is not a simple matter. It is not like the changes trees undergo in the fall or how a mountain range erodes over millions of years. What we are speaking about is the change of genetic inheritance. Genetic material that is changed in minute ways over many, many, many generations gives rise to the fantastic diversity of life we see today.

The central ideas of evolution are: all life has a history, it changed over time, and different species share common ancestors. Life has an evolutionary "family tree." By studying a species' inherited characteristics and other historical evidence, we can reconstruct evolutionary relationships and represent them on a "family tree" called a phylogeny. This "tree" is an hypothesis about the relationships among organisms. It is by no means perfect. Scientists constantly reevaluate the hypotheses and restructure them based on new evidence. For example, evidence discovered in the last 50 years now suggests birds may have originated from dinosaurs.

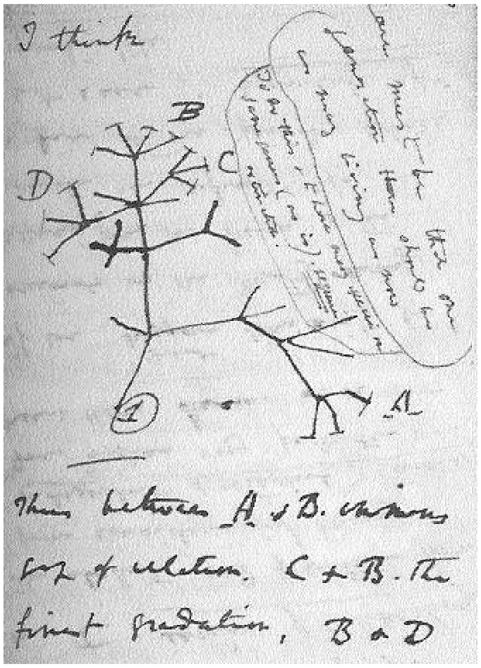
A phylogeny is similar to reading a family tree. The roots of the tree represent the ancestral lineage and the tips of the branches represent the descendents of that ancestor. When a lineage splits (speciation) it is represented as a branch on a phylogeny. When a speciation event occurs, a single ancestral lineage gives rise to two or more daughter lineages.

Phylogenies trace patterns of shared ancestry between lineages. Each lineage has a part of its history unique to itself and parts that are shared with other lineages. Before Darwin, biologists organized life forms like the rungs of a ladder, lowest forms to highest forms. Phylogeny shows the relationship between the lineages, not that one is "higher" or "more evolved than another.

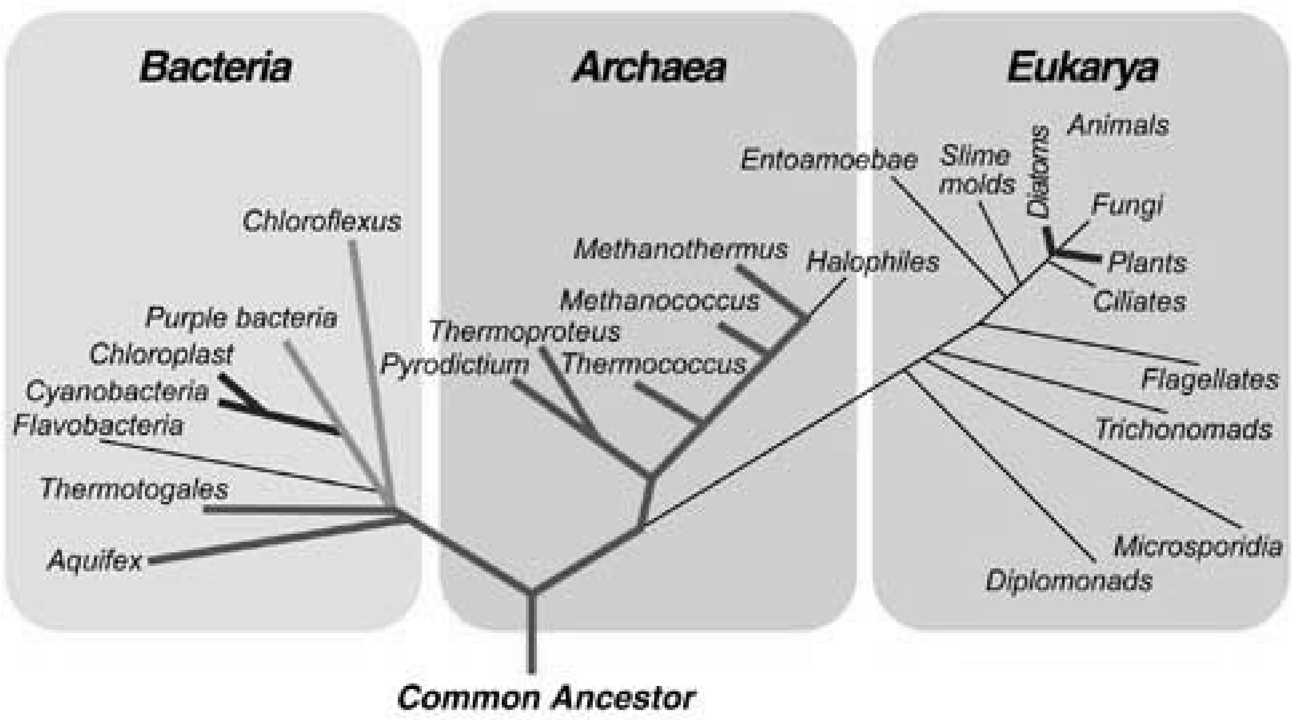
We use homologous characteristics to build the phylogeny. An homologous characteristic is one that may appear different in two dissimilar species but is fundamentally the same and therefore points to a common ancestry. An example would be the homologous characteristics of four limbs (Tetrapods). Birds, bats, mice and alligators all have four limbs. Both the ancestor of tetrapods and their descendents have inherited the feature of having four limbs; so the presence of four limbs is an homology.

Not all characteristics are homologies. Birds and bats have wings, but mice and alligators do not. Does this mean that birds and bats are more closely related to each other than mice and alligators? When one examines the wing of a bird and that of a bat, we see some major differences. Bat wings have skin stretched between their bones; birds have feathers extending along their arm. This suggests they didn't inherit wings from a common winged ancestor. They are similar in function, but different in structure. Bird and bat wings are analogous, having separate evolutionary origins, but they evolved to serve the same function. Sometimes this is called "convergent evolution."

We know these changes in organisms didn't happen overnight. The history of the earth is roughly 3.5 billion years old. If we condensed this into a single minute, we would have to wait for about 50 seconds for multicelluar life to evolve, another four seconds for vertebrates to appear, another four seconds for flowers to evolve and only 0.002 second to first see "modern" humans. . Time can be represented on phylogenies by drawing the branch lengths in proportion to the amount of time that passed since that lineage arose. They can also be adjusted to show when lineages split and/or went extinct.



Darwin's sketch of an evolutionary tree of related organisms--the first of its kind, appearing on page 36 of Notebook B.



This tree of life--or phylogenetic tree--traces the pattern of descent of all life over millions of years into three major branches: Bacteria, Archaea, and Eucarya. Until 1996, however, scientists had confirmed the existence of only two of those branches. And although Earth's biomass is largely microbial, most previous studies focused primarily on a tiny portion at the tip of the Eucarya branch, the region containing animals and plants.

Genetic Variation

Just how do the selective forces work that allow evolution to occur? Fundamental to the process is genetic variation. Evolution only occurs when there is a change in gene frequency within a population over time. These genetic differences are inheritable and can be passed on to the next generation. This long term change is what really matters in evolution. Let's say a population of beetles is 90% green in color and 10% brown in color. Generations later the brown beetles make up 70% of the population; a change in gene frequency has occurred. How did this happen?

Let's look at these possible events:

1. A mutation could have caused parents with genes for green to have offspring with a gene for brown coloration.

2. A migration of brown beetles may have entered the genetic pool making the genes for brown beetles more frequent in the green beetle population.

3. Imagine a fire swept over the beetles, causing many more green beetles to be killed than brown ones. The next generation would have more brown beetles.

These chance changes from generation to generation are known as **genetic drift**.

4. What if green beetles were easier for birds to spot and be eaten than brown beetles? The brown beetles are more likely to survive and pass their brown genes to the next generation.

This is known as **natural selection**.

All of the above can cause changes in the frequency of genes in a population and are mechanisms of evolutionary change. Natural selection and genetic drift can only occur if there is a genetic difference in the population. **A beetle population would remain unaffected by changes if the genes were all the same.**

Without genetic variation the basic of evolutionary change cannot operate. There are three primary sources of genetic variations:

Mutations – changes in the DNA: In most situations, evolutionary change is based on the accumulation of many mutations.

Gene Flow – any movement of genes from one population to another.

Sex – can introduce new gene combinations into a population.

Mutations

A mutation is a change in DNA, the hereditary material of life. The DNA of an organism affects its looks, behavior, and its physiology.

Any change in its DNA could cause a change in all aspects of its life. Mutations are random; it may or may not be useful to the organisms. Not all mutations matter for evolution. Somatic mutations occur in non-reproductive cells and can't be passed on. Only those that can be passed on to the offspring (called germ line mutations) matter to large scale evolution. They also have to cause some really important phenotypic changes, like resistance to an insecticide or be lethal to an organism.

Persons in farming and animal breeding have used the idea of selecting traits in plants and animals for decades. Only those animals or plants with desirable characteristics are allowed to reproduce. Farmers have cultivated numerous popular crops from wild mustard by artificially selecting for certain desirable traits. Broccoli was developed by suppression of flower development; kohlrabi came about by the enhancement of the lateral meristems.

Adaptation

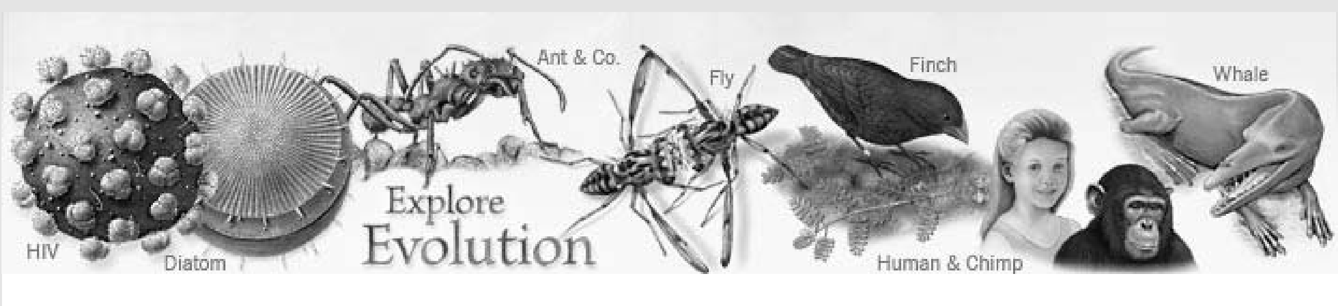
Adaptations are common in populations and are produced by natural selection. It can take many forms: The mimicry of leaves by insects is an adaptation for evading predators. A bush that produces toxins is preventing other plants from growing which reduces its competition for water and nutrients. Echolocation in bats is an adaptation for catching insects at night.

What is a species?

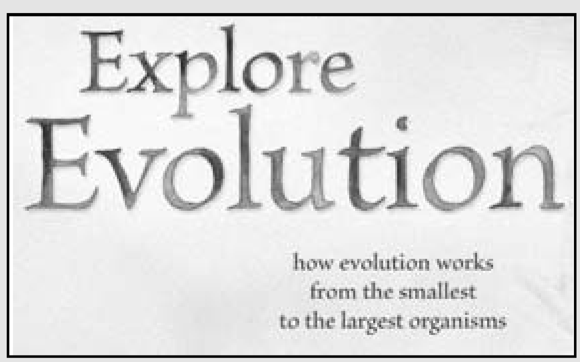
At this point, we need to define species. It is often defined as a group of individuals that can interbreed in nature. This definition is not a “cut and dry” situation. If two lineages of maple trees look quite different, but can occasionally form hybrids, should we consider them as separate species? The boundaries of “species” are often a blur, maybe because humans invented it for their own convenience.

Speciation is a splitting event which produces two or more separates lineages. When this happens, genetic changes result in two separate species. For example, let’s say there is a population of wild, fruit eating beetles laying their eggs on ripe peaches. A flood occurs, washing the peaches and beetle eggs several hundred miles downstream. This population is too far downstream for the individuals to mate with the population upstream. Ecological conditions are also slightly different than those upstream. The downstream beetles evolve under different selective pressures and experience different random events than the upstream population. Morphology, food preference, and courtship displays change over the course of many generations of natural selection. Even if the two could be rejoined, the difference between them makes them incompatible to each other. The lineage now has split, forming two new species. In most “real life” situations, it is difficult to put the whole story together from the available evidence; but the known evidence suggests this sort of process does occur. Scientists believe geographic isolation, rivers, mountains, and continental drift are common means for the process of speciation to begin.

Scientific evidence supports the central conclusion of evolutionary theory, that life on Earth has evolved and that species share common ancestors. Biologists are not arguing about these conclusions. They are still trying to determine how evolution happens. That is not an easy task. It involves collecting data, proposing hypotheses, creating models, and evaluating the works of other scientists. These are all activities that we can and should hold up to a checklist and ask the question: “Is what we are doing science?”



Explore Evolution, a new multimedia exhibition, will open at the University of Kansas Natural History Museum and Biodiversity Research Center on Nov. 1. The free exhibition, which will be on display for the next two years, gives visitors the opportunity to understand and experience how scientists conduct research on evolution.



Problem Concepts in Evolution: Cause, Purpose, Design, and Chance

The following article is condensed from an article written by Eugenie C. Scott.
www.ncseweb.org/resources/article/695_problem_concepts_in_evolution

The manner in which teachers present the concepts of **cause, purpose, design, and chance** to students can make a significant difference to students' acceptance of evolution.

To members of the non-scientific public, these terms can have meanings, such as religious implications, beyond those applied in science. Religion is allowed, by its nature, to recognize supernatural causation. Science is neutral to religion. Science does not attempt to promote or denigrate religious explanations for natural processes. Science is an attempt to explain natural processes using things observable and testable and cannot be altered by rules or beliefs associated with a nonmaterial or supernatural world. Science requires testing of alternate explanations. In truth, science must be neutral to religion for practical as well as philosophical reasons.

Scientific Meaning of Cause: Modern biologists recognize ***two classes of causes: proximate (or immediate) and ultimate or indirect causes***. Goldsmith describes proximate cause as "what one can see" and ultimate causes as invoking "the concept of adaptation of organs to their environment as well as evolutionary inferences..." The immediate cause for plumage difference in male and female birds is hormonal differences, but the indirect cause is natural selection .

The public tends to answer most questions about the natural world through proximate cause-- the causation factors and their interactions--such as why storms form? But divine causes may be used to infer why the storm occurred at a certain location for a particular reason, such as punishment for the inhabitants. Only proximate or immediate causes and secondary or remote causes are what science is concerned with, not the philosophical reason behind the event. The goal in presenting science and evolution is to do so in a way that prevents the student from having to choose between science and their religious beliefs.

Scientific Meaning of Design: Scientists use design in two ways. One definition of design is a structure which allows an organism to do something. The long, slender bill of a hummingbird used to extract nectar from flowers is an example of design. In this sense, design refers to parts that work together to accomplish something. The purpose of a structure is "what it is good for," and the design is how it achieves its purpose.

Design in the public definition is linked with teleology, as the means by which a goal is achieved, or that if a watch exists, so does a watchmaker. A self imposed theory, like natural selection is difficult for most people to understand. In science, we limit ourselves to natural explanations which guide the process of change. Orthogenesis or the idea that you will have a specific "thing" at the end of the process is another "public" concept for design but not a process of evolution.

Let's look at the automobile which has undergone a number of changes since it first appeared, most of them to help it do its "job" better. The first automobiles did not look all alike: some were powered by steam, others by a gas engine, and one even used a device like a watch spring. Some were steered by a stick, others by a wheel, and one by applying a brake device to the opposite set of wheels! The automobile evolved many lines of "cars" to its present form, each with many unique features for acheiving its purpose. Design in evolution is not going to create an "end for all times" of a particular life form--it is a continuous process.

Chance: Scientific Meanings In science, chance means it will occur according to a known probability, such as the possibility of a coin landing on "heads is fifty percent. In evolution, chance is referred to as changes which may occur due to fluctuations of genes or traits in a nonselective environment. **Random** is when occurrences are governed by equal probability. In a bowl of numbers from 1-50, the numbers 59 and 24 have equal probability of being drawn.

Chance: Public Meanings In newspapers, on television and in other popular media, chance and random are more often used nonprobabilistically such as when we read about "random violence." The writers do not mean that everyone has an equal chance of being sampled, but that such violence is meaningless and purposeless. It is the most frightening form of violence because it is unpredictable — you just don't know what will happen, or why. **Ironically, scientists use the concepts of random and chance to make predictions, which is the direct opposite of their connotation in ordinary usage.**

One must be clear that the use of chance is the scientist's probabilistic term, not the public's "unpredictable, senseless" use. In approaching evolution, we will have to be specific about how we use "chance and random" and be careful not to leave students with the impression that natural selection is a "chance" process.

National Association of Biology Teachers Statement on Teaching Evolution

This statement has been edited to fit into this space. Complete text can be found at www.kabt.org

As stated in The American Biology Teacher by the eminent scientist Theodosius Dobzhansky (1973), "Nothing in biology makes sense except in the light of evolution." This often-quoted assertion accurately illuminates the central, unifying role of evolution in nature, and therefore in biology. Teaching biology in an effective and scientifically-honest manner requires classroom discussions and laboratory experiences on evolution.

Modern biologists constantly study, ponder and deliberate the patterns, mechanisms and pace of evolution, but they do not debate evolution's occurrence. The fossil record and the diversity of extant organisms, combined with modern techniques of molecular biology, taxonomy and geology, provide exhaustive examples and powerful evidence for genetic variation, natural selection, speciation, extinction and other well-established components of current evolutionary theory. Scientific deliberations and modifications of these components clearly demonstrate the vitality and scientific integrity of evolutionary theory.

This same examination, pondering and possible revision have firmly established evolution as an important natural process explained by valid scientific principles, and clearly differentiate and separate science from various kinds of nonscientific ways of knowing, including those with a supernatural basis such as creationism. Evolutionary theory, indeed all of science, is necessarily silent on religion and neither refutes nor supports the existence of a deity or deities.

Accordingly, the National Association of Biology Teachers, an organization of science teachers, endorses the following tenets of science, evolution and biology education:

• The diversity of life on earth is the outcome of evolution: an unpredictable and natural process of temporal descent with genetic modification that is affected by natural selection, chance, historical contingencies and changing environments.

• Evolutionary theory is significant in biology, among other reasons, for its unifying properties and predictive features, the clear empirical testability of its integral models and the richness of new scientific research it fosters.

• The fossil record, which includes abundant transitional forms in diverse taxonomic groups, establishes extensive and comprehensive evidence for organic evolution.

• Natural selection, the primary mechanism for evolutionary changes, can be demonstrated with numerous, convincing examples, both extant and extinct.

•Natural selection-a differential, greater survival and reproduction of some genetic variants within a population under an existing environmental state-has no specific direction or goal, including survival of a species.

• Adaptations do not always provide an obvious selective advantage. Furthermore, there is no indication that adaptations-molecular to organismal-must be perfect: adaptations providing a selective advantage must simply be good enough for survival and increased reproductive fitness.

•The model of punctuated equilibrium provides another account of the tempo of speciation in the fossil record of many lineages: it does not refute or overturn evolutionary theory, but instead adds to its scientific richness.

•Evolution does not violate the second law of thermodynamics: producing order from disorder is possible with the addition of energy, such as from the sun.

• Although comprehending deep time is difficult, the earth is about 4.5 billion years old. Homo sapiens has occupied only a minuscule moment of that immense duration of time.

•When compared with earlier periods, the Cambrian explosion evident in the fossil record reflects at least three phenomena: the evolution of animals with readily-fossilized hard body parts; Cambrian environment (sedimentary rock) more conducive to preserving fossils; and the evolution from pre-Cambrian forms of an increased diversity of body patterns in animals.

• Radiometric and other dating techniques, when used properly, are highly accurate means of establishing dates in the history of the planet and in the history of life.

• In science, a theory is not a guess or an approximation but an extensive explanation developed from well-documented, reproducible sets of experimentally-derived data from repeated observations of natural processes.

•The models and the subsequent outcomes of a scientific theory are not decided in advance, but can be, and often are, modified and improved as new empirical evidence is uncovered. Thus, science is a constantly self-correcting endeavor to understand nature and natural phenomena.

• Science is not teleological: the accepted processes do not start with a conclusion, then refuse to change it, or acknowledge as valid only those data that support an unyielding conclusion. Science does not base theories on an untestable collection of dogmatic proposals. Instead, the processes of science are characterized by asking questions, proposing hypotheses, and designing empirical models for research about natural events.

• Providing a rational, coherent and scientific account of the taxonomic history and diversity of organisms requires inclusion of the mechanisms and principles of evolution.

• Similarly, effective teaching of cellular and molecular biology requires inclusion of evolution.

• Specific textbook chapters on evolution should be included in biology curricula, and evolution should be a recurrent theme throughout biology textbooks and courses.

•Students can maintain their religious beliefs and learn the scientific foundations of evolution.

• Teachers should respect diverse beliefs, but contrasting science with religion, such as belief in creationism, is not a role of science. Science teachers can, and often do, hold devout religious beliefs, accept evolution as a valid scientific theory, and teach the theory's mechanisms and principles.

• Science and religion differ in significant ways that make it inappropriate to teach any of the different religious beliefs in the science classroom. Opposition to teaching evolution reflects confusion about the nature and processes of science. Teachers can, and should, stand firm and teach good science with the acknowledged support of the courts. In Epperson v. Arkansas (1968), the U.S. Supreme Court struck down a 1928 Arkansas law prohibiting the teaching of evolution in state schools. In McLean v. Arkansas (1982), the federal district court invalidated a state statute requiring equal classroom time for evolution and creationism. Edwards v. Aguillard (1987) led to another Supreme Court ruling against so-called "balanced treatment" of creation science and evolution in public schools. In this landmark case, the Court called the Louisiana equal-time statute "facially invalid as violative of the Establishment Clause of the First Amendment, because it lacks a clear secular purpose." This decision-"the Edwards restriction"-is now the controlling legal position on attempts to mandate the teaching of creationism: the nation's highest court has said that such mandates are unconstitutional. Subsequent district court decisions in Illinois and California have applied "the Edwards restriction" to teachers who advocate creation science, and to the right of a district to prohibit an individual teacher from promoting creation science, in the classroom. Courts have thus restricted school districts from requiring creation science in the science curriculum and have restricted individual instructors from teaching it. All teachers and administrators should be mindful of these court cases, remembering that the law, science and NABT support them as they appropriately include the teaching of evolution in the science curriculum.

On TRACKS is published by the Kansas Department of Wildlife & Parks several times during the school year.

The purpose of On TRACKS is to disseminate information and educational resources pertaining to the natural, historic, and cultural resources of the prairie, emphasizing Kansas ecology. Information is presented from the perspective of current scientific theory.

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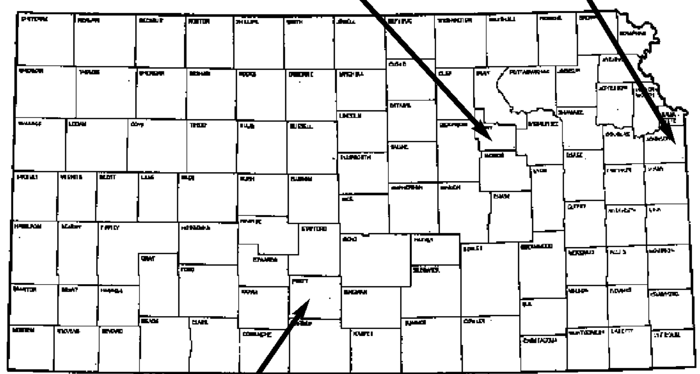

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