

Why Study Evolution?

We study evolution for the same reasons that we study any subject — the thirst for knowledge, to understand the past and predict the future, and to organize our world. But the subject of evolution also has huge relevance to our world and current issues that concern all of us. Evolution was happening 150 million years ago when dinosaurs dominated the Earth, was happening in the 1830s when Charles Darwin landed on the Galapagos Islands during the voyage of the *Beagle*, and it is happening today. It is occurring in every living species on the planet, right now. Evolution is not just about fossils. It is also about molecules, genes, mutations, populations, and sex in living organisms. All of these things are primary sources of data about evolutionary processes that occur when organisms try to survive and reproduce. Evolution also is about rigorous analyses — what we must do with the data to say something that is scientifically defensible. So if you thought that evolutionary biology was limited to dusty old curators in dusty old museums, think again. Scientists at universities, research centers, and museums are conducting some of the most sophisticated analyses of any kind today, using some of the best prepared specimens, most advanced techniques, and fastest computers available. Nothing in biology can be truly understood without first understanding evolution.

Defining "Science"

Reminding students of what science is and what science is not, is important to establish before introducing the concepts of evolution. Science and all of our technological advances are based upon **hypotheses** that are developed, tested, and refined (or refuted) through the **scientific method**. The scientific method provides observable and measurable **evidence** collected through observation and/or experimentation. Nothing outside the observable or measurable can be called scientific. Therefore science cannot inform public law, morals, ethics, or religion. For example, science can estimate the depth of the ocean; this is both observable and measurable. Science cannot answer the meaning of life; this is neither observable nor measurable.

The scientific definitions and uses of the words hypothesis, fact, evidence, theory, and law often cause confusion because they have different meanings when used outside of the field of science. A **hypothesis** is an educated guess, based on **facts** (observations or data), which



A caricature of Charles Darwin from the London Sketchbook (1874).

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evidence • Information accumulated through observations of phenomena that occur in the natural world, or which are created as experiments in a laboratory. Scientific evidence usually goes toward supporting or rejecting a hypothesis.

hypothesis (pl. hypotheses) • An "educated guess," based on evidence, concerning how or why a phenomenon occurs; see also theory, law.

scientific method • The process of scientific inquiry for investigating phenomena, acquiring new knowledge, and correcting and integrating previous knowledge. To be called scientific, a method must be based on observable, measurable evidence collected by observation and/or experimentation.

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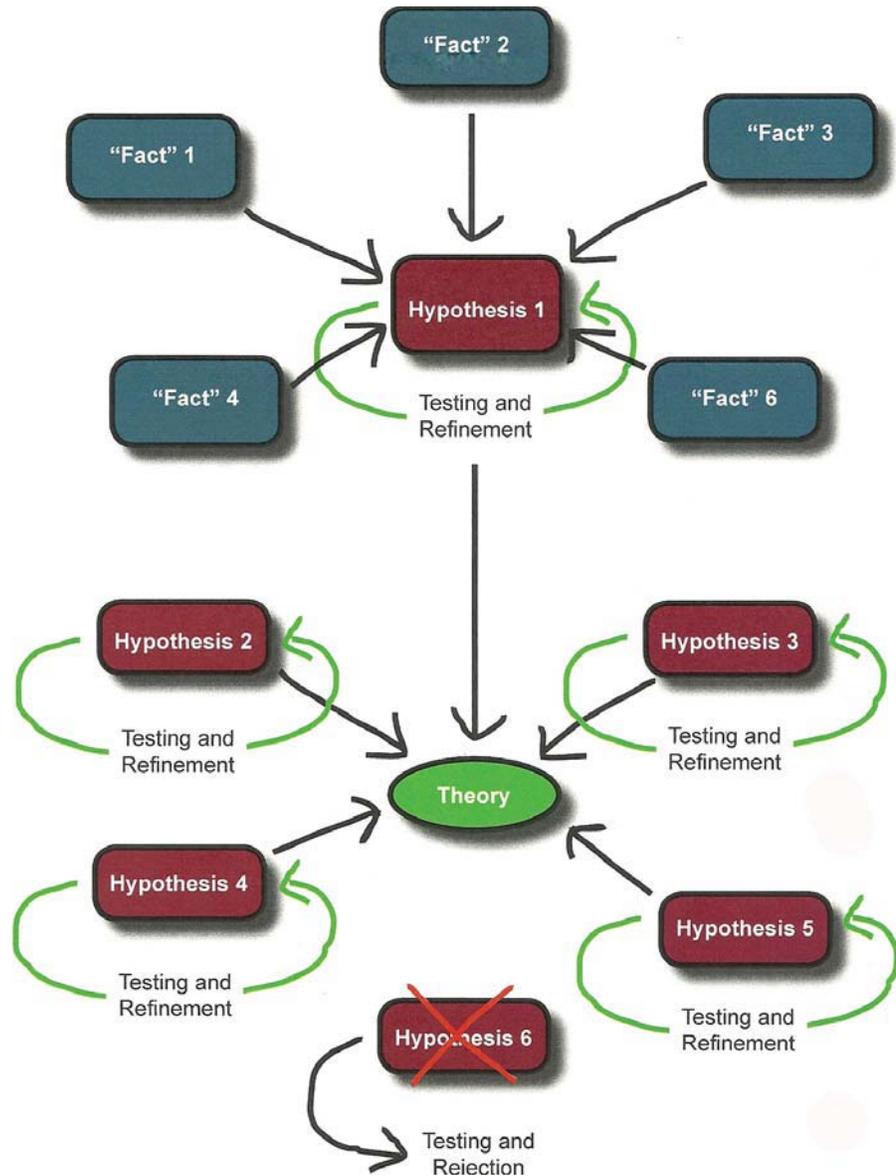
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fact • An objective and verifiable observation; in contrast with a hypothesis or theory, which are intended to explain or interpret facts.

law • An established principle thought to be universal and invariable; see also hypothesis, theory.

theory • A hypothesis that has become “widely accepted” after rigorous testing; see also hypothesis, law.

can be experimentally tested. If a hypothesis is experimentally shown to be incorrect, it is refuted and either rejected or refined. If a hypothesis is repeatedly tested and always shown to be correct, the hypothesis is supported and accepted. A large number of highly tested, never refuted, hypotheses form the basis of evidence that supports a **theory**. A scientific theory is the synthesis of a large number of accepted hypotheses. Scientists continue to test, refine, and add additional accepted hypotheses to make a theory more concise, but an entire theory is rarely ever completely discarded or replaced. A scientific **law** expresses a theory as a less complex summary statement, often as a mathematical equation, such as $E=mc^2$.



Note that the scientific use of the word “theory” is fundamentally different from its common usage. In everyday English, a theory is a mere guess or speculation. However, scientific theories are the highest order of scientific explanation and are generally accepted to be true by the scientific community as a whole. Evolution is a scientific theory based upon evidence provided by all fields of biological science. In physics, a similarly supported theory is gravity; in chemistry, a good example is the atomic theory.

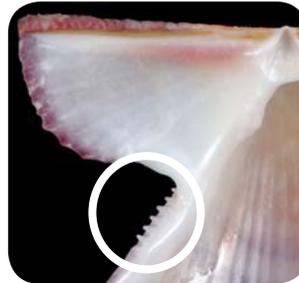
Defining "Evolution"

The word evolution means change. In biological terms, **evolution** is **inherited** change within a **lineage**. In other words, evolution occurs when inherited changes from **generation** to generation within one **population** of a **species** give rise to a new appearance, a new genetic code, and ultimately, a new species.

Scallops – today mainly members of the bivalve family Pectinidae – have been alive on Earth since the early Triassic Period, approximately 240 million years ago. They are characterized by “ears” (called **auricles**) on the shell and a notch below one of them through which a set of elastic threads (called a **byssus**) emerge to help hold the scallop, at least during its juvenile life, to the sea bottom. At the edge of the byssal notch in most scallops is a comb-like set of spines (called the **ctenolium**) that separate and support the byssal threads. The direct ancestors of scallops were scallop-like bivalves of the family Entoliidae, which lived during the Paleozoic and Mesozoic Eras (400-65 million years ago). Entoliids had auricles and a byssal notch only as juveniles, but they did not have a ctenolium. The ctenolium – a defining feature of the modern family Pectinidae – is a feature that evolved within the scallop lineage.



A living scallop, *Caribachlamys sentis*, from the Florida Keys. The notch between the auricle (at left) and the main body of the shell is the **byssal notch**, through which the foot and byssus extend.



The **ctenolium** (in white circle) of *Caribachlamys sentis* from the Florida Keys helps separate and support its byssal threads. Many adult scallops do not use a byssus beyond the juvenile stage, and so lose the ctenolium as they grow larger.



The family Entoliidae is considered ancestral to modern scallops. This is *Entolium aviculatum* (PRI 14077, 2.25 cm diameter), from the Carboniferous Period of Henry County, Missouri. The auricles are to the right and left of the **umbo** at top center.



An unidentified fossil scallop (Pectinidae, PRI 14076, 3.7 cm diameter), from the Jurassic Period of Bradford-on-Avon, England. This specimen is preserved in a similar way to the older Entoliidae (at left).

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auricles • Ear-shaped structures on the shells of scallops, one of their defining characteristics.

byssus (adj. *byssal*), **byssal threads** • A tuft of long, tough filaments which are formed in a groove of the foot, and issue from between the valves of certain bivalve mollusks, by which they attach themselves to rocks, etc.

evolution • Inheritable change within a lineage, or the change that occurs between generations within one population of a species. This refers of course to change expressed from one individual to another, but we are usually most interested in the changes so great that the later generation is considered a different species.

generation • A single step or stage in the succession of natural descent.

inherited • Derived from a pre-formed genetic code present in an ancestor.

lineage • Line of descent from an ancestor.

population • A group of organisms, all of the same species, which occupies a particular area.

species • A group of organisms formally recognized as distinct from other groups; the taxon rank in the hierarchy of biological classification below genus; the basic unit of biological classification, defined by the reproductive isolation of the group from all other groups of organisms.

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ctenolium • A comb-like structure along the ventral edge of the byssal notch in scallops in which the byssal threads rest.

metamorphosis (pl. **metamorphoses**) • A change in body form and often habits of an animal following the embryonic stage during normal development.

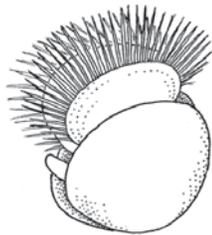
natural selection • The process by which living forms with traits that better enable them to adapt to specific environmental pressures, e.g., predators, changes in climate, or competition for food or mates, will tend to survive and reproduce in greater numbers than others of their kind, thus ensuring the perpetuation of those favorable traits in succeeding generations. Also called **Darwinism**.

umbo • Rounded or pointed extremity of a bivalve shell, often projecting above the hinge line, that reflects the early growth stage (= oldest part of the shell) and includes the prodissoconch (larval shell) and adjacent convex area; also called the "beak."

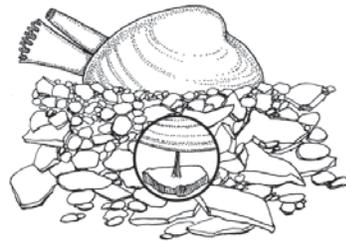
veliger • Planktonic larval type characteristic of most mollusks (including bivalves), characterized by a ciliated locomotory organ (velum) which is either discarded or resorbed at metamorphosis.

Not all biological change is evolution. The metamorphosis, growth, and physical changes of an individual organism are biological changes but are not evolution.

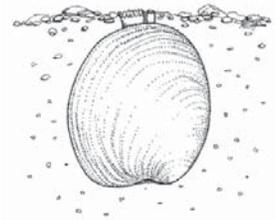
A baby clam spends the first part of its life as a free-swimming, two-shelled larva called a **veliger** - its locomotory apparatus is a pair of ciliated lobes called a **velum** that propels it through the water. Eventually, the larva grows a foot, settles onto the ocean bottom, and **metamorphoses** into a **benthic** organism, resorbing its velum and growing in size. At this stage, its foot secretes strong but elastic **byssal threads** to stabilize it in the sediment. The clam's appearance changes quite dramatically from juvenile to adult; notice that the adult (below right) no longer uses a byssus, and has relatively shorter siphons than the attached juvenile.



Veliger larva



Attached juvenile



Adult

Evolutionary change does not necessarily mean improvement or progress. Evolution does not follow a linear progression from simple to complex or primitive to advanced. Evolution is occasionally depicted, inaccurately, as a ladder leading progressively from "lower" to "higher" organisms (usually with humans at the top). In reality, however, evolution is more accurately depicted as a tree with many branches. Some species become extinct, some mutations and variations fail, and simple organisms can be highly adapted to their environments. The phrase "more evolved" does not necessarily mean "better."

There is often confusion between the words evolution and Darwinism. Long before Charles Darwin, many scientists understood that evolution occurred but they could not explain how. Darwin's publication, *On the Origin of Species* (1859), provided the first mechanism of evolution, **natural selection**. The terms Darwinism and natural selection can be used interchangeably. Other mechanisms of evolution have also been accepted. Therefore, evolution is species change over time and Darwinism is just one of the mechanisms of how these changes occur.

Why study evolution? Evolution is the unifying theory that explains all biological science. All life is connected and none of it can be fully understood without the theory of evolution. Imagine trying to study chemistry without understanding that molecules are made of atoms (atomic theory). Evolution allows us to understand the past, predict the future, and map the organization of our world. Evolutionary scientists from all fields of biology (paleontology, molecular biology, genetics, etc.) are using the most sophisticated research techniques and technologies to explain life. Understanding the evolution of bivalves can help prevent their extinction, prevent the spread of invasive species around the world, and can even help scientists date geological events. More information about the importance of evolution can be found in the **Evolution in Everyday Life** section.

Teaching Evolution with Confidence

No biology class would be complete without studying evolution and it is a requirement of the national and state education standards. Unfortunately a large number of teachers in American public and private schools feel unable or unprepared to teach evolution in their classrooms. The *TFGEB* is designed to provide the background information needed by teachers to acquire a foundation of knowledge to use in teaching evolution.

Here are some suggestions on how to approach and prepare to teach evolution.*

1. Prepare but don't ignite. Be ready to address common misconceptions about evolution but do not assume that your students already have the misconceptions.
2. Use what you have available, and the comparative method. A simple comparison of two different but familiar organisms is enough to raise and address important evolutionary questions.
3. Get back to basics. Review the basic terminology of science. Evolution cannot be dismissed as "just a theory."
4. Clearly distinguish between the occurrence and mechanisms of evolution. There is no debate among knowledgeable biologists about whether evolution occurs. There is still vigorous debate about how it occurred.
5. Emphasize that evolution explains observations and answers questions. All lines of available evidence – from comparative anatomy to embryology to genetics – support evolution as the explanation for life's diversity on Earth, past and present.
6. Don't equivocate. The theory of evolution is universally accepted by all scientists that know anything about the subject. To tell students that "scientists aren't sure" or that there are "weaknesses" in the theory is simply lying to them.
7. Know the material. Evolution is a broad topic and it is impossible to know everything. However, the more you know, the more confidence you will display.
8. Seek help when (or, ideally, before) you need it. There are a large number of resources available for background information, activities, and dealing with the sensitive topic of creationism.
9. Evolution is not a belief. Students might ask if you "believe in evolution." Beliefs are faith-based, whereas science is fact-based. The theory of evolution is based upon established, highly tested, scientific evidence. One can either accept the scientific evidence or refute it (through experimentation), but one cannot "believe" in evolution.

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For more tips, see *Tools for Ambitious Science Teaching* [<http://tools4teaching-science.org>].

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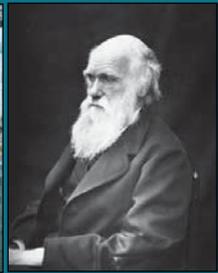
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The Teacher-Friendly Guide to Evolution

Using Bivalves as a Model Organism

By Paula M. Mikkelsen & Robin Henne



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