EvoEdu: Evolution Education

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This document is designed for use in a middle school science classroom. I intended it to be printed out and read, probably as a homework assignment. It assumes no prior knowledge of biological concepts.

This text presents evolution in a manner that's actually clear, coherent, much more interesting than a textbook, and accessible to the layman. Each section has a few problems designed to both make the student think about what they've read and to discourage hunting through the text for answers. On the next two pages, you'll find a short quiz that covers the material found in this document, and an answer key for the quiz and reading problems.

The text is divided into three main sections: an explanation of what evolution is and how it works, the evidence for evolution, and what arguments are commonly leveled against it (and why they aren't valid). The 'controversial' subject matter of the final category may not be appropriate for a middle-school classroom; bear this in mind when you make your lesson plans. Assign as much or as little of the text as you see fit; it's designed to still make sense no matter where you stop reading.

Name:

Class Period:

Date:

Part One

1. Give a brief overview of what the theory of evolution is, in your own words.
2. Name three of the five observations evolutionary theory is based on.
3. What does it mean if one gene outcompetes another?

Part Two

1. Give an example of a case where evolution was observed occurring, or was observed immediately after it occurred. Be sure to explain what was happening in the population when it evolved.

Part Three

1. A friend of yours claims that evolution cannot be true because it is purposeless. Is this argument valid? Why?
2. This friend then goes on to claim that evolution cannot be true because there are no transitional fossils. Is this argument valid? Why?

Answer Key

Quiz

Part One

1. Evolution is change in a population over time. In any population there is variation due to random mutations. This variation can lead to different individuals having different numbers of offspring, and thus spreading their genes. Eventually, new genes outcompete new genes, and new species are formed.
2. Any three of the following: no two organisms are identical, these differences are heritable, a population produces more offspring than will survive to reproduce, some organisms have more offspring that survive to reproduce than others, and these differences in reproductive success are because of heritable differences.
3. It means that one gene disappears (or at least becomes less common) while another one takes its place, and spreads throughout the population.
4. No. This is possible because some species die out without evolving into new species, while others evolve into many different ones.

Part Two

1. I apologize, but this one you're going to have to figure out yourself – you know your kids a lot better than I do.

Part Three

1. No. Something does not have to have a purpose to exist.
2. No. There are, in fact, transitional fossils.

Problems

Part One

1. No two organisms are identical, these differences are heritable, a population produces more offspring than will survive to reproduce, some organisms have more offspring that survive to reproduce than others, and these differences in reproductive success are because of heritable differences.
2. They die out. They outcompete (or take the place of) other, less well-equipped organisms.
3. A mutation
4. Something getting at the idea of differential reproductive success causing changes in gene frequency.
5. Old body parts that served a different function.
6. They should produce something approximating a phylogenetic tree.

Part Two

7. Fossils are found in rock layers in reverse order of the direction that they most likely evolved.
8. Yes. They will likely talk about the Caribbean island lizard experiment and London mosquito evolution.

Part Three

9. Pick five of the following. Misunderstandings: evolution is just a theory, evolution doesn't explain where life or the universe came from, evolution is purposeless, evolution is godless, scientists don't know everything, and "If we evolved from monkeys, why are there still monkeys?" Factually wrong: there are no transitional fossils, there is controversy over whether evolution is true, and there are no transitional fossils.

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What is **EVOLUTION**, and how does it work?

Evolution is one of the most important ideas Evolution is one of the most important ideas ever thought of by mankind. It explains virtually everything in biology, and has countless uses, from computer science to philosophy. It is a crucial tool for understanding the world around us. Yet, despite evolution's importance, public opinion (though not the opinions of scientists) is divided on whether it's true. People have a surprisingly poor understanding of evolution, and hold a number of misconceptions about the idea. This is not their fault. Despite evolution's importance, it's hard to find information about it that's easy for non-scientists to understand. That's what this text is designed to help with. This is an introduction to evolution, and will explain what evolution is, how it works, the evidence for it, and whether the arguments against it hold up. That said, let's see what evolution is all about.

Five Observations

Evolution is based on five observations. First, no two organisms, or living things, are identical. Look at your dog, your best friend's dog, and your neighbor's dog. Even if they're all the same gender and breed, they are all noticeably different.

Second, these differences can be passed down from parent to child. Look at horses. Individual horses tend to be very different from one another, but the children, or offspring, tend to be quite similar to their parents.

Third, a population produces more children, more offspring, than will survive to reproduce. Look at oak trees. They make countless acorns each year, but only a handful of those acorns will ever grow into large enough trees to make their own acorns.

Fourth, some individuals have more offspring, more children, that survive to reproduce than others. Some individuals are barren, and others die young. The survivors have different numbers of offspring. Even those with identical numbers of offspring will have different numbers that survive long enough to reproduce on their own. One butterfly could have no offspring that survive to maturity. Others may have dozens.

The fifth and most important observation is that some individuals have more offspring that survive to reproduce because of their inherited differences. A dog that is resistant to disease will probably pass that on to its pups, and so have more pups that survive to reproduce than another dog. A wild horse that can run faster will probably have more foals than one that runs slowly. The slow one may have a foal or two, and then be eaten by wolves. The fast one will probably survive to have many foals, most of which will be able to outrun the wolves long enough to have offspring of their own. An oak tree that makes acorns that are better able to pass through an animal's stomach will probably have more offspring than another oak. The other oak will lose most of its acorns to animals, while the tougher oak's acorns will survive to sprout and make tough acorns of their own. A butterfly that doesn't need to eat as much nectar will be less likely to starve before it can reproduce, and be able to spend more time looking for mates. It will probably have more offspring, many of which will probably have to eat less than normal.

It doesn't take much probing to that realize these observations are true, and scientists draw an interesting conclusion from them: some members of a species will outcompete others. There are never enough resources to go around, whether the resource is food, shelter, or safety. Some members of a species will be better equipped to get those resources, or to make better use of them.

Because of this, they will have more offspring than the others. The better-equipped living things, or organisms, pass their abilities on to their offspring. Over time, the better-equipped organisms outcompete the other ones.

This will be easier to understand with an example. You have a population of lobsters. Some have stronger claws than others. There is only so much food, and only so many places to hide. The strong-clawed lobsters are better able to hunt, and better able to fight the weak-clawed lobsters for hiding places. After one generation, many weak-clawed lobsters starved because they couldn't get as much food. Other weak-clawed lobsters were eaten, because they couldn't fight off the strong ones for their hiding places. Most of the strong-clawed lobsters, though, were able to find enough food and hide, and so they survived. Because, at the end of the generation, you have many more strong lobsters than weak ones, when the lobsters reproduce, they make a lot more strong-clawed young than weak-clawed ones. After a few generations of this, the weak-clawed lobsters are mostly wiped out, while the strong-clawed lobsters are doing just fine. They outcompeted the weak-clawed ones, and lobsters are now different things from what they were before. The nature of lobsters was changed over time.

1. What are the five observations evolution is based on?
2. What happens to worse-equipped organisms over time? What happens to better-equipped organisms?

Genes and Selection Pressures

All organisms, or living things, have have different characteristics, called traits. An organism's traits are controlled by its genes, which are coded instructions found in its cells. An organism passes on many of its genes to its offspring. If it reproduces sexually, like humans, it passes on half its genes. If it reproduces by splitting itself in half, it passes on all its genes. Because every individual is different, a population has a lot of different genes in it.

An individual's genes help determine how many offspring the individual is going to have that survive to reproduce. For example, individuals with genes that help them get more food are probably going to survive longer, and so have more offspring. Another example is antibiotic-resistance genes. If a colony of bacteria is exposed to the drug penicillin, those with genes that make them resistant to being killed by the drug will survive to have offspring that reproduce.

Sometimes, an individual is born that has a mutation, or change in its genes, that makes it different from the rest of the population. For example, Lance Armstrong, the famous bicyclist, has a mutation from a few generations ago that gives him an oversized heart.

Over time, versions of genes that do a better job or a more important job replace those that don't. This will be easier to understand with an example.

Antelope live on the plains of Africa, and their only protection from being eaten is running away. One antelope is born with a mutation that lets it contract its muscles more quickly. This lets it run faster than the other antelopes. We'll call this antelope "the mutant antelope," because it has a mutation. Because it is faster, it is able to outrun the other antelopes in its herd, so that the predators eat the slower antelopes, and not the mutant one. Because of this, the mutant antelope lives a long life, and so is able to have many offspring. It passes on its mutation to some of its offspring, who also survive to have mutant offspring. The predators are still eating antelope, so the size of the herd isn't getting any bigger overall, but the number of mutant antelope in the herd is increasing. Eventually, all the non-mutant antelopes are eaten, and all the members of the herd have the mutation. After a few mutations, the herd is so different from all the other herds that it can no longer breed with members of other herds. It's now a totally different species of antelope.

Here are some other, briefer, examples of evolution. For example, a new disease forces organisms to evolve a better immune system. Or, a species arrives on an island, which doesn't have many resources, and so evolves to be smaller so as to use fewer resources. Or, new organisms arrive in an area, and compete with pre-existing organisms, and force both to evolve. Eventually, either one is wiped out or one evolves to get its food from a different source. All of these are quite common examples of evolution.

All populations have many different versions of genes, because genes mutate. What genes do better jobs changes over time, because the demands nature puts on plants and animals changes over time. A combination of changing genes and changing demands for genes creates new species over time.

The way all of evolution works is the phrase, "Mutations at random cause nonrandom reproduction."

3. What is it called when an organism is born with a change in its genes?
4. Why do populations change over time?

Descent with Modification

Because evolution is organisms changing over time, and eventually creating new species, the process has been called "descent with modification." One species may give rise to a half-dozen new ones, while others may die out as a dead end. Remember that evolution acts at the population level, so one population in a species can evolve, while the others remain unchanged, or evolve in different directions. If you were to map the lines of descent, and show what species evolved into what other species, you wind up with a sort of bushy tree. You start with some species at the bottom of the tree. Some die out without evolving into new species. Others evolve into several. Thus, some branches stop, others keep going, and others split into several branches.

New body parts regularly form from old parts that served a different function. For example, feathers first evolved in dinosaurs as a sort of modified scale that kept the animal warmer. Some of the smaller feathered dinosaurs moved into the trees. There, those with longer feathers used them as parachutes. Over time, mutant feathers developed that could be used to glide. Those with the mutant gliding feathers were successful and spread the gene very quickly. A series of more mutations created the modern bird's flight feather. The mutations that created the flight feather were coincidences, but the fact that they spread throughout the population was not. Since the dinosaurs with better feathers survived longer to produce more offspring, the dinosaurs with mutant feather genes outcompeted the others. Again, mutations at random cause nonrandom reproduction.

5. Where do new body parts come from?
6. Draw the lines of descent with modification of a hypothetical group of species. Start with one species, and map out how it might evolve into new species over time. Think "bushy tree."

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What is the **EVIDENCE** for evolution?

So what actual evidence is there that evolution actually happens? Unsurprisingly, there's a huge amount. Let's look at some of the best evidence.

Fossil Evidence

First, we have tens of thousands of fossils that clearly show bushy trees of descent, with one type of organism evolving into others (or several others) over time. The fossils are found in the earth in reverse of the order in which they evolved, with the fossils of the species at the bases of their bushy family trees found deeper in the rock than fossils of the organisms that evolved from them. Dating of different layers of rocks with radioisotope dating unquestionably supports the idea that deeper rocks are older rocks, and that deeper fossils are older fossils.

One fossil that clearly demonstrates the forces of evolution at work is that of an animal called the Tiktaalik. The Tiktaalik is a species that was part of the way between a fish and an amphibian. The animal has very clear fish parts, but also very clear amphibian parts. It's a world-class example of evolution being caught in the act.

Organismal Evidence

For centuries, scientists relied mostly on fossils as support for evolution. Fossils are useful, but not as accurate as working with living organisms. Now that we can study living organisms in controlled conditions, we can go beyond fossils for evolutionary support.

In 2006, a team of researchers from Harvard University introduced a lizard-eating species of predator onto a small Caribbean island. Over the next six months, the average lizard leg length increased greatly. This makes sense, because longer-legged lizards can run faster to get away from the predator. Then, in the six months after that, average leg length decreased even beyond the average length at the start of the study. Slowly, all the fast-running lizards were being eaten up, and the only ones that could survive were those in the trees – and short legs give you a lower center of gravity, helping you climb. The evolution of the lizards stopped on a dime, reversed direction, and went even faster than before. This is a major change in a population in only a year, or (for these lizards) two generations. This experiment shows that serious evolution can occur in a very short time.

In London, the most common species of mosquito is known as Culex pipiens. In 1863, the world's first underground railway opened in London. It was the start of the now-famous London Underground. In 1940, the Germans began bombing London, and many Londoners took shelter in the railway tunnels, where they would be safe. While they slept, they were bitten by mosquitoes. Upon analysis, it was discovered that these mosquitoes were a new species. It seems as though some common Culex pipiens mosquitoes entered the Underground, which has a very different set of selection pressures from aboveground London, and started evolving. Between 1863 and 1940, in less than one hundred years, the pipiens mosquito evolved into a new species, called Culex molestus. The two species have different genes, do not tend to breed with one another, and have very different behaviors. While the pipiens mosquito bites birds in the night skies over London, molestus prefers mammals – mainly the rats that infest the tunnels and the humans that infest the stations. This is definitive proof of one species of organism evolving into another, and in at most 77 years.

These two examples, using real organisms, show definitively that evolution not only happens, but is still happening to this day. The best part is, they're repeatable. If you're in London, grab a mosquito in the Underground and one outside your flat; they even look different. You might have a little more trouble reproducing the lizard experiment, unless you happen to have a few Caribbean islands handy, but the folks who did the experiment are already planning to repeat it.

All of these examples you've seen here are not only conclusive evidence for evolution, but they're just a small sample of the total data that's out there. Evolution is a fact, and this has been proven time and time again, to the point where it's possibly the best-supported scientific theory in history.

7. In what way to fossils provide support for evolutionary theory?
8. Can evolution be observed to occur within years or dozens of years, rather than millions? If so, name two examples. If not, why not?

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What are the **ARGUMENTS** against evolution?

The theory of evolution is opposed by a number of groups outside the scientific community. Here, we'll look at some of their most popular arguments, and then see if they stand up to inspection.

Arguments Based on Misunderstandings

Evolution is just a theory.

In casual conversation, the word "theory" means a hunch, or an idea that's not supported by much evidence. In science, though, the word means something very different. To the scientist, the word "theory" means an idea supported by countless experiments and countless pieces of data. Calling something "a theory" is as close as a scientist can get to calling something "truth."

Evolution doesn't explain where life or the universe came from.

That's entirely correct, and also entirely beside the point. Evolution explains what happens to life when you already have life and a universe, much like how gravity describes what happens to mass when you already have it. Saying that evolution doesn't explain where the universe came from is like saying that gravity doesn't explain where matter comes from – it's entirely true, but entirely beside the point.

Evolution is purposeless.

Just because something is purposeless doesn't mean that it does not exist. Water doesn't have a purpose when it flows across a table, but that doesn't mean that it doesn't flow. Evolution is undeniably purposeless, but it still exists.

Evolution is godless.

Evolution does not require a god in order to work. Neither does a kitchen stove. Being godless doesn't mean that stoves don't work, nor does it mean that evolution doesn't work.

Scientists don't know everything.

No, scientists do not know everything. It's the fact that scientists do not claim to know everything that lets them refine their ideas based on new observations. It's science's flexibility that makes it strong.

If we evolved from monkeys, why are there still monkeys?

First things first: we didn't evolve from monkeys. We have a common ancestor with monkeys – our ancestors branched off from the same small, ape-like organism millions of years ago. Second, even if we did evolve from monkeys, evolution works on the level of the population, not the species. There are still bird-biting pipiens mosquitoes flying around London. Only part of the population went underground and evolved. Just because a new species evolved from one population of an old species doesn't mean that all the populations of the old species went extinct.

Arguments That Are Factually Untrue

There are no transitional fossils.

There are transitional fossils. One example of this is the Tiktaalik, the half-fish, half-amphibian fossil that we looked at earlier. Other classic transitional fossils include the dinosaur-to-bird Archaeopteryx, the doglike-mammal-to-whale Ambulocetus, and the apelike-mammal-to-human Australopithecus, though there are countless others.

There is controversy over whether evolution is true.

Something along the lines of 99.9% of working biologists accept evolution. The Discovery Institute, an evolution-challenging organization, sometimes collects the names of PhDs who oppose evolutionary theory. The number of actual, working biologists on their lists is minimal at most. Most people on those lists don't even have jobs in the scientific community, let alone biology degrees. Among biologists, there simply isn't any controversy.

Evolution cannot be tested.

This idea is quite popular, but as we saw with the lizard experiment and the E. coli bacteria experiment, evolution can be tested.

These are some of the most common arguments used against evolution. The thing is, though, that none of them hold up particularly well under scrutiny. If you continue learning more about evolution (and I encourage you to!), you'll probably run across some new arguments. Most of these arguments will be based on misunderstandings of the evidence or how evolution works, so if you do encounter an argument against evolution, do a little research. It's virtually certain someone has explained why the argument doesn't stand.

9. All of these arguments are either factually wrong or based on a misunderstanding. Pick five arguments and decide which category each falls into.

This text covered a staggering amount of material. You learned about the five observations on which evolution is based. You learned how mutations create new genes, how nonrandom reproduction can change what genes are common, and how changes in genes over time changes populations and produces new species. In other words, you learned that mutations at random cause nonrandom reproduction. You learned about descent with modification. You learned about some of the evidence supporting evolution, about fossils, rock layers, the Tiktaalik, the Caribbean island lizard experiment, and about London mosquito evolution. Finally, you learned why the arguments against evolution don't hold up.

Evolution is fantastically important – one of the most important ideas ever thought of by mankind. Despite evolution's certain truth, much of the public clings to other ideas, ideas supported by neither logic nor evidence. With the information you've read today, you are equipped to understand what both sides of the evolution debate are saying.

-Tristan Zimmerman