

This document is designed for use in a High School biology classroom. I intended it to be printed out and read, probably as a homework assignment. It assumes prior knowledge of basic biological concepts like genes, alleles, and that proteins are made of amino acids. If your students are unfamiliar with these ideas, a more accessible version is available at EvoEdu.com/learn.html in .doc, .rtf, .mp3, and illustrated online formats.

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). 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. Which three of the following are selection pressures that would act in a reasonably direct fashion on the population given?
 - a) The frequency of the noise made by cicadas in the area; goldenrod flowers in Minnesota.
 - b) The food supply; bacteria in a Petri dish with different sorts of organic chemicals.
 - c) How quickly funguses decompose the area's rotten logs; lions on the African savanna.
 - d) The color of the paint; refrigerators in a warehouse.
 - e) Females having a preference for mating with individuals that look a certain way; anteaters in a South American rainforest.
 - f) The color of dead leaves on the ground; snakes in a forest.
2. Name three of the five observations evolutionary theory is based on.
3. What does it mean if one gene outcompetes another?
4. As time passes, does one species usually evolve into a certain number of other species? If so, what is the number? If not, explain how this is possible.

Part Two

1. Devoting a short paragraph to each, give two examples where evolution was observed occurring, or was observed immediately after it occurred. Be sure to explain what selection pressure(s) was/were involved in each example.

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. b, e, f
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. Them to all survive.
2. Inherited differences between the wolf with more surviving pups and the ones with fewer.
3. They die out. They outcompete (or take the place of) other, less well-equipped organisms.
4. Mutations.
5. A paragraph including the concepts of differential reproductive rates and genes outcompeting other genes.
6. Old body parts that served a different function.
7. They should produce something approximating a phylogenetic tree.

Part Two

1. Fossils are found in rock layers in reverse order of the direction that they most likely evolved.
2. You would expect similar amino acid sequences for the proteins of closely-related organisms, and quite different amino acid sequences for the proteins of distantly-related ones. This is exactly what you find.
3. Yes. They should definitely mention short generation times. It would be great if they also mentioned strong selection pressures.
4. Predators, food supply, and prey, respectively.

Part Three

1. Mostly, they're misunderstandings of what evolution is, how it works, or how science works.
2. There are far more factually wrong arguments. Only Intelligent Design is blatantly unscientific. The rest are disprovable by simple facts.

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

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. According to observation three, if a wolf has 25 pups over the course of its life, what wouldn't you expect to happen to all of them?
2. According to observation five, if one wolf in a group has 90% of its pups survive to reproduce, while the others in the group have only 20% survive, what would be one possible cause?
3. What happens to worse-equipped organisms over time? What happens to better-equipped organisms over time?

Genes and Selection Pressures

Evolution acts on something called a gene pool. If you count every gene in a population, and add up every copy of an allele that appears more than once, you get a gene

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pool. Gene pools are controlled by things called selection pressures.

A selection pressure is anything that affects which individuals have more offspring that survive to reproduce. One example of a selection pressure is the food supply. Individuals with genes that help them get more food are probably going to survive longer, and so have more offspring. Another example is antibiotics. If a colony of bacteria is exposed to the drug penicillin, those resistant to being killed by the drug will survive to have offspring that reproduce. There is a selection pressure towards traits that help you get more food, and towards traits that help bacteria resist penicillin.

Sometimes, an individual is born that has a mutation that makes it different from the rest of the population. Sometimes the mutation is bad, and selection pressures stop it from spreading. Other times, the mutation is good, and selection pressures usually spread it around the population. For example, Lance Armstrong, the famous bicyclist, has a mutant allele from a few generations ago that gives him an oversized heart. Mutations and selection pressures are constantly changing the gene pool.

Selection pressures select towards a gene that helps an organism have more offspring that survive to breed, and more and more of the population gets it over time. Eventually, better genes outcompete genes that didn't do the job as well, and the entire population is changed over several generations. This can be a bit of a tricky concept, so let me give a few examples.

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. We see how the selection pressure of not being eaten is spreading the mutation through the population. 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.

Let's look at a fungus as another example. This fungus breaks down rotting wood in a forest to get nutrients. When a fungus reproduces with another fungus, it shoots out fungus seeds, or spores. One fungus has a mutation that lets it tolerate acid better than all the others. This mutation neither helps nor hurts the fungus. There is no selection pressure for or against it, similar to eye color in humans. The mutation survives in the population, but it doesn't really spread, because there is no selection pressure. A few thousand years after this, an area of the forest gets wet and turns into a swamp. Most of the forest remains unchanged, but that new swamp area has a totally different set of selection pressures. Swamp water is a little bit acidic, and most of the fungus population can't handle this acid. A few, however, have that acid-tolerating gene, and spread into the swamp. There are no other fungi in the swamp, so there's no competition for food. The acid-resistant fungus quickly occupies the entire swamp. There are now almost as many acid-resistant

fungi in the swamp as there are normal ones in the forest. Because the swamp and the forest have completely different sorts of selection pressures, different mutations will spread through the swamp and forest fungus populations. Over time, and after a few more mutations spread, the forest fungus and swamp fungus will become completely different species.

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 diversity in their gene pool, because genes mutate naturally when errors are made copying the genes to pass them on to offspring. These mutations cause the gene pools to change over time. Selection pressures change over time, because nature changes over time. A combination of changing selection pressures and diverse, changing gene pools creates new species over time.

You have to remember, though, that an organism does not control its evolution. Evolution is simply a process, like water flowing across a tabletop. Selection pressures force the gene pool in different directions; the gene pool has no control over its future. Evolution is not planned, guided, or marching towards a predetermined goal. Evolution is simply what happens when the environment places selection pressures on the gene

pool. Again, think of water flowing across a tabletop.

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

4. What introduces new alleles into the gene pool?
5. Write a short paragraph explaining how selection pressures act on a population.

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. A species does not have to go extinct to give rise to another. 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.

Continuing with the idea of "descent with modification," any change in a population must be advantageous in order to spread quickly. Otherwise, selection pressures could not speed it along, and it often disappears. If it's harmful, it simply will not spread. Even if the harmful mutation, combined with another mutation, would be very helpful, it still won't spread. That's why animals don't have springs for legbones. That would require at least two mutations: one to make their bones springy, and another to warp their legbones into spring shapes. But having non-springy spiral bones would prevent you from moving well, and having non-spiral springy bones

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would just make you flop around like a fish out of water. New features have to evolve by steps, and one step along the way is hugely disadvantageous, so spring-legs cannot and do not evolve.

However, 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.

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

What is the **EVIDENCE** for evolution?

So, while it's plain that evolution seems logical, it doesn't necessarily mean it's true. What matters more than logic is evidence. Is evolution supported by evidence? Evolution is one of the most well-supported theories accepted by modern science. More importantly, it makes predictions which are later shown to be true. If a theory can predict, that's powerful evidence that it's true.

Let's look at some of the best evidence for evolution, and also look at some of the predictions that evolution makes.

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.

The information found in fossils and rock layers also makes predictions. In 2006, a team of researchers from the University of Chicago began looking for a fossil of an animal part-way between a fish and an amphibian. They searched rock layers known to have formed in areas of fresh water between 380 and 363 million years ago, when fish first started to evolve into amphibians. There, they discovered a fossil of a transitional species midway between fish and amphibians. This creature, which they named

the Tiktaalik, is a world-class example of an animal acted on by selection pressures to evolve between two very different forms. Evolutionary theory perfectly predicted where, when, and what the scientists would find. Evolutionary theory frequently makes predictions like this.

1. In what way do fossils provide support for evolutionary theory?

Molecular Evidence

For centuries, scientists relied mostly on fossils as support for evolution. Fossils are useful, but not as accurate as working with molecules or living organisms. With the development of modern techniques, we can go beyond fossils for evolutionary support.

Genes control the chemical makeup of proteins. Over time, mutations in the genes cause changes in the amino acid sequences of the proteins. In most proteins, most of the amino acids don't affect the shape. Changing them doesn't change the protein, and so evolution neither works against these mutations, nor helps them along. What you would expect, then, is for more closely-related organisms to have few differences between their amino acid sequences due to mutations, but for more distantly-related organisms to have lots of mutation differences in their amino acid sequences. The more time that's passed, after all, the more time there's been to have these mutations.

This is exactly what you find – again, evolution makes a successful prediction. The cytochrome c protein causes an important step in the breakdown of food for energy. Almost any organism that breaks down food has a cytochrome c protein. Only about a third of the amino acids in cytochrome c keep it in its specific shape. The other two thirds can mutate fairly freely. Chimpanzees and humans, which evolutionary theory and fossils predict to be very closely related, have identical cytochrome c proteins. No visible

mutations have happened since we split off from a common ancestor, because not enough time has passed. Humans and yeast, though, which are extraordinarily different creatures (yeast isn't even an animal) have over 50 differences between their cytochrome c amino acid sequences. All species of organisms show this pattern with mutations; the more distantly related, the more mutations you have. The molecular evidence is exactly what evolutionary theory predicts.

2. If evolution is true, what similarities would you expect to find in the proteins of closely- and distantly-related organisms? Is this what you find? If not, why?

Organismal Evidence

So evolution can be conclusively shown to have happened. But it would be a lot more convincing if it could be shown to still be happening now. As it so happens, there are thousands of experiments showing this. Let's look at some of the latest and best.

In 2006, a team of researchers from Harvard University introduced a lizard-eating species of predator onto a small Caribbean island. Understandably, the size of the population of the only species of local lizard dropped by half. Scientists found that over the first six months of the study, the surviving lizards had, on average, much longer legs. Then, in the next six months, average leg length radically decreased far beyond the average length before the predator was introduced. The evolution of the lizards stopped on a dime, reversed direction, and went even faster than before.

This data shows some very interesting things. When the predator was first introduced, the lizards with shorter legs, who can't run on the ground as fast, were eaten more than those with longer legs. During this time, the lizards were reproducing, making a new generation of longer-legged lizards. Then, they started moving into the trees. Shorter legs and a lower center of gravity are

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a real help in trees, so the shorter-legged lizards severely outcompeted the longer-legged ones. While that was going on, this generation was breeding, making a new shorter-legged generation. This is a major, macroevolutionary 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.

Even bigger changes can be seen in bacteria, because they have such short generation times, and so can evolve in very little time. Since 1988, a professor at Michigan State University has been tracking twelve populations of the intestinal bacteria *E. coli*. He has kept them in containers with very little of the sugar glucose, but a great deal of the simple chemical citrate. One of the important characteristics of *E. coli* is that it is very good at eating glucose, but cannot eat citrate. So, there's a strong selection pressure towards something that will allow the *E. coli* bacteria to eat citrate, since any citrate-eating bacteria would flourish. Every five hundred generations, the researcher froze samples of the bacteria, so that he could go back later and track any changes. Though it took tens of thousands of generations, the *E. coli* bacteria eventually developed the ability to eat citrate. This took three independent mutations, which evolved at three different times. None of the mutations do very much on their own, but when working together, they enable the *E. coli* to thrive and do something it's never been able to do before. The new strain of *E. coli* proceeded to outcompete the rest of the strains. Because of the freezing, the researcher could actually track the evolution of the *E. coli* over time. This is, indisputably, mutations at random causing nonrandom reproduction.

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 three 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. You could probably do the bacteria experiment in your garage. 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.

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3. Can evolution be observed to occur within years or dozens of years, rather than millions? If so, what could cause evolution to work that fast? If not, why not?
4. Name one selection pressure that caused an observed change in the lizard experiment. Do the same for the *E. coli* experiment and the London mosquito observation.

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 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." Scientists continue to refine and test the theory of gravity, the theory of relativity, atomic theory, and the theory of evolution. Over the centuries, scientists disproved countless theories and created others to improve their understanding of the nature of life, the world and the universe.

Could the theory of evolution be disproven? Certainly, but only by the same system of undisputed facts, rigorous methodologies and structured experiments scientists use to expand our understanding.

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 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.

Evolution isn't necessary.

Some people say that whether or not evolution is true, it doesn't really change anything for us right now. Since evolutionary theory creates so much strife and division, why not set it down for the sake of harmony? However, evolution is very relevant. Evolution is the only tool we have to predict how nature will react to our actions. When your doctor prescribes an antibiotic, if you don't take all of it, you'll only kill the bacteria vulnerable to it, while the tougher ones survive and reproduce. Only by taking all your antibiotics will you kill all the bacteria, and not create a selection pressure towards the tougher ones. Without evolution, we would never know that people not taking their antibiotics is one of most important things creating drug-resistant infections. We need to understand evolution: if we don't understand it, we'd never know how nature could change to possibly harm us.

Achilles' heel

Some challengers of evolution will point to one piece of information that they say definitively proves that evolution cannot be true, like a supposed fossilized human

footprint next to a fossilized dinosaur print. Usually, these pieces of information wind up being misunderstandings, but even those that haven't been invalidated yet are not going to disprove evolution. Evolution is supported by a mountain of evidence. To disprove it, you will need a mountain of contrary evidence. If you have a mountain of evidence for something, and a handful of data against, odds are that data is a fluke. The only way to show that it isn't a fluke is to get a huge amount of evidence showing that evolution isn't true. Contrary to what some (not all) challengers of evolution may tell you, a huge amount of contrary evidence does not exist. So trying to find an "Achilles' heel" in evolutionary evidence cannot work, because you'll need far, far more than just a handful of information.

Gaps in evolutionary history

Some challengers of evolution point to gaps in the fossil record as evidence that evolution is poorly supported, as there are dark periods where we don't know what happened. First, this doesn't say anything about how evolution works; all it says is that we don't know all the evolutionary changes that have taken place over history. Second, more gaps does not mean less knowledge. If you suspect that species A evolved into species D, you have one gap. If you find a fossil from species B which looks like it is a transitional fossil between A and D, you now have two gaps. When you find a fossil from species C, between B and D, you now have three gaps. Yes, you have more gaps. But that's because you actually know more now.

1. All these arguments are based on misunderstandings. What sorts of misunderstandings are common in these arguments?

Arguments That Are Factually Untrue

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

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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.

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 Archaeopteryx (between dinosaurs and birds), the Ambulocetus (between doglike mammals and whales), and the Australopithecus (between apelike mammals and humans), 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.

Evolution is Darwinism.

Many challengers of evolution call evolution "Darwinism," after Charles Darwin, the man who first thought of the idea of natural selection. It makes biologists look like they accept everything Darwin wrote at face value. Nothing could be further from the truth. Much of what Darwin had to say has been disproven. Biologists only care about what the evidence shows, not what people had to say. Evolution is just that: evolution, not Darwinism.

Irreducible complexity.

Irreducible complexity is the idea that some traits couldn't have evolved naturally, because if they're missing just one mutation, they don't work, and so selection pressures couldn't push toward the development of those traits. It's an interesting idea, but it doesn't stand up to the facts. Remember the experiment where *E. coli* bacteria evolved to eat citrate? That took 3 different mutations. If the bacteria were missing just one of those mutations, it wouldn't be able to eat citrate. If irreducible complexity is true, then those bacteria could never have evolved the way they did. However, they did evolve, (and thanks to the freezing of samples every 500 generations, you can actually track the evolution) so it can't be true. Irreducible complexity simply doesn't hold up to testing.

Intelligent Design

Some challengers of evolution advocate an idea called "Intelligent Design." Intelligent Design states that, because of irreducible complexity, an Intelligent Designer must be responsible for changes in organisms over time. This idea has three problems: it relies on irreducible complexity, it's a "science stopper," and it's not testable.

First, irreducible complexity isn't true. We saw this in the *E. coli* citrate experiment. So, Intelligent Design has no basis. Second, the idea of Intelligent Design blocks scientific progress. As soon as you ascribe a natural phenomenon to supernatural causes, you stop investigating it. The supernatural cannot,

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by definition, be studied (if it could, it would just be natural), and so science just stops.

Third, science relies on experiments. You can't run an experiment to test Intelligent Design. It's simply not possible. Before conducting an experiment, the researcher has to decide what the different possible outcomes of the experiment would suggest about what he's studying. So, if you're going to run an experiment on Intelligent Design by, say, putting bacteria in a flask and watching them, you would first have to decide, "OK, if the bacteria do any of these four things, then there isn't an Intelligent Designer, but if they do any of these five things, then there is one." You can't do that. You cannot identify what features you'd expect an intelligently designed universe to have. You can't test for God. Because of these three flaws, Intelligent Design not only isn't valid, it's not even science.

These are all 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.

2. All these arguments are either factually wrong or completely unscientific. Assuming that each argument can fall into only one of these two categories, decide the category for each argument. Which are there more of on this list? Support your claim.

This text covered a staggering amount of material. You learned about the five observations on which evolution is based. You learned how mutations add new genes to the gene pool, how selection pressures change the gene pool through nonrandom reproduction, and so how change in the gene pool 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, silent mutations, the Caribbean island lizard experiment, the E. coli citrate 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