Big Picture on EVOLUTION

ISSUE 5
JANUARY 2007

Did Darwin see the likeness? See page 2.

FACE TO FACE WITH THE PAST: fossils are one way in which we can glimpse the past.

"Nothing in biology makes sense except in the light of evolution."

When biologist **Theodosius Dobzhansky** wrote these words in 1973, he was reflecting on the coming together of two strands of thinking: **evolutionary change**, kick-started by Darwin in the mid-19th century, and **genetics**, a subject whose origins go back to the same era, with Mendel's studies, but only really got going early in the 20th century. **Genetics provided the mechanism by which natural selection could occur.** This was the famed '**modern synthesis**'.

Since then, with a few refinements and many unanswered questions, **the general principles of Darwinian evolution have been widely accepted**. At least, they have been in the scientific world. In wider society, a significant proportion of people remain sceptical.

Why should this be? **Why does Darwinian evolution raise controversy when, say, quantum mechanics scarcely registers on the public consciousness?** This issue of *Big Picture* looks at the theory of evolution, the evidence that supports it, unanswered questions and the history of public reaction.

In doing so it touches upon some of the most profound questions we can ask. Where did we come from? How did life start? **What forces control the destiny of life on Earth?** And does science enable us to answer these questions?

FIND OUT MORE →

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DARWIN'S BIG IDEA

In the mid-19th century, two natural historians independently arrived at almost identical theories. One, Charles Darwin, is remembered as the father of evolutionary thinking. The other, Alfred Russel Wallace, is much less well known.

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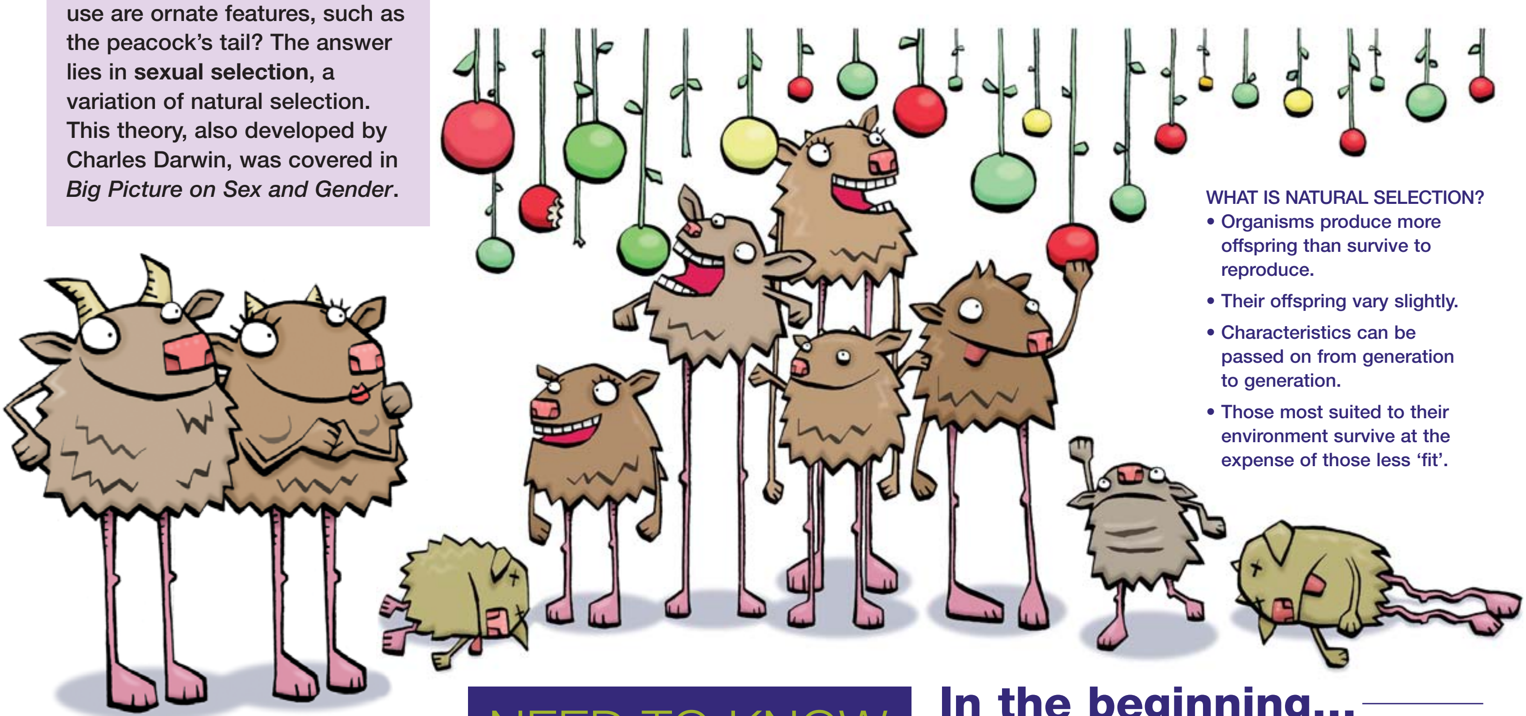
NON-KISSING COUSINS: The hyrax (left) is, surprisingly, the closest living relative of the elephant (right). Another close relative is the dugong (sea cow) – evolutionary relationships are not always obvious.

SEXUAL SELECTION

According to natural selection, heritable features should have survival advantage. But what use are ornate features, such as the peacock's tail? The answer lies in **sexual selection**, a variation of natural selection. This theory, also developed by Charles Darwin, was covered in *Big Picture on Sex and Gender*.

Their shared insight was that living species were not fixed, but were the product of a gradual process of change driven by **natural selection**: the survival and reproduction of organisms suited to their environment, at the expense of those less successful.

Darwin laid out his ideas in *On the Origin of Species by Means of Natural Selection*, possibly the most important scientific book ever published. Biology would never be the same again.



WHAT IS NATURAL SELECTION?

- Organisms produce more offspring than survive to reproduce.
- Their offspring vary slightly.
- Characteristics can be passed on from generation to generation.
- Those most suited to their environment survive at the expense of those less 'fit'.

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NEED TO KNOW

Genotype: Genetic characteristic of an individual (e.g. having gene or genes for red hair).

Phenotype: The physical traits of an individual (e.g. having red hair). Dependent on genotype and interactions with environment.

Allele: A version of a gene. Many genes have a number of different alleles, owing to small variations in gene sequence.

Genome: The complete set of genetic instructions of an individual or species.

Sexual reproduction: Where an offspring's genes come from two parents.

Asexual reproduction: Where an offspring is genetically identical to its (single) parent.

In the beginning...

Mainstream scientific theories hold that life came into existence and developed through natural causes. But many cultures have developed alternative explanations for our existence.

The world that we live in contains a rich tapestry of cultures and each one has its own, often very rich beliefs about where we come from. These explanations often draw upon common themes – a **supreme creator being** or beings, the **stars**, planets and heavenly bodies, or important features of the **environment** such as mountains or lakes.

Inuit

The Inuit, who live on the ice from Greenland to Alaska, believe that one day land rose out of the water and a raven secured this floating land by stabbing its beak into it.

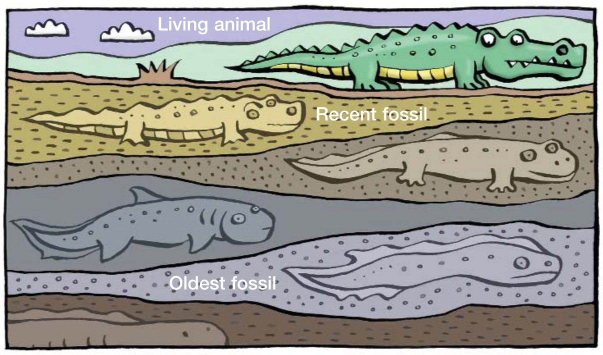
Ancient Egypt

In ancient Egypt, the god Ra arose from a blue lotus flower after an interaction between the primordial forces of water, air, darkness and eternity. Ra created a wife called Hathor and they had a son called Horus.

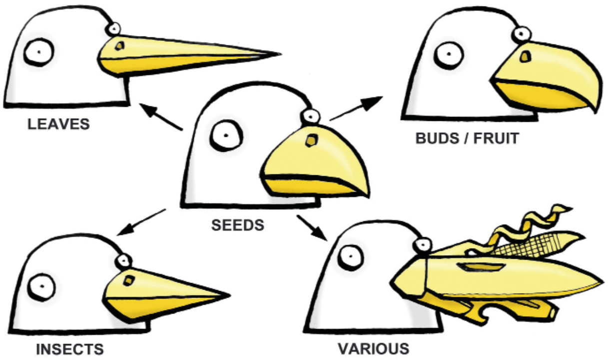
The case for...

Darwin brought together many lines of evidence to support his theory. Since his time, other studies have added to the weight of evidence for evolution.

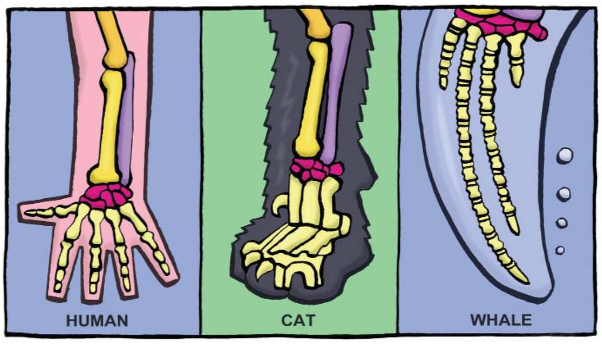
THE FOSSIL RECORD...



ADAPTIVE RADIATION...



COMPARATIVE ANATOMY...



Caught in a drift

A random process of drift can also change the genetic make-up of a species.

A change in DNA might be beneficial but is usually harmful. Often, though, it won't make a blind bit of difference. This is known as a **neutral change**.

If the environment neither favours nor discriminates against this change, Darwinian theory suggests that it will have no evolutionary impact. In fact, **neutral changes are important, thanks to a random process known as genetic drift**.

Because of chance events in breeding, the frequency of alleles may fluctuate or 'drift' over time. **How much evolutionary change is due to drift is not certain**.

So the presence of a common allele does not necessarily mean it has been through the filter of natural selection: it may just have been lucky.

Changes in allele frequency due to chance have probably had a big impact on people, because we are derived from a very small **founder population** – perhaps only a few thousand early humans survived a climate catastrophe around 70 000 years ago (possibly linked to a supervolcano eruption).

Cultural evolution

Genes are not the only way information can be passed on.

Biological evolution is central to our existence and acts through our **genes**. But there are other ways that something can be passed on from generation to generation.

Culture, our system of beliefs, values and knowledge, is passed on through interaction between people, for example by storytelling or writing.

One of the strongest cultural systems is language, which shows clear signs of evolutionary change. Linguists have distinguished families of languages. English, for example, is part of the **Indo-European family**, which includes Sanskrit and other Asian tongues as well as European languages.

Social customs

Many social customs are deeply ingrained. Some are maintained by selective pressures. Take for example, gift-giving. In Polynesian culture in the 1800s, if a gift was received and nothing given in exchange, then the receiver would lose their spiritual source of guidance and wealth, so it made sense for people to exchange presents.

In other cases, **it can be difficult to disentangle biological and cultural explanations**. In most cultures, **incest** is taboo. This could be a **social convention**, but it could also have a **biological basis**. Inbreeding is often harmful to the health of offspring, so mechanisms preventing it can have a selective advantage.

MECHANISMS OF EVOLUTION

The discovery of genes provided a mechanism for **heredity** and a way to explain how natural selection operated.

Darwin's theory of evolution depends on information being passed from parent to offspring. In Darwin's day, however, the mechanisms of heredity were a complete mystery.

Curiously, though, at almost exactly the same time **Gregor Mendel** was carrying out experiments that would lay the foundations of a new discipline – **genetics** – and provide Darwin's missing mechanism.

We now know that hereditary information is contained within **genes**. They carry information in a form that can change – creating variation – and yet still be passed on.

Key moments in genetics and evolutionary biology

1910–11	**Thomas Hunt Morgan** maps a gene for a physical trait (**white eyes** mutation) to a fruit-fly **sex chromosome**.
1930s	R A Fisher, J B S Haldane, Sewall Wright and others use mathematical techniques to combine genetics and evolutionary biology in the '**modern synthesis**'.
1944	Oswald Avery shows that **DNA** is the cell's hereditary material.
1952	Watson and Crick discover **DNA double helix.**
1960s	**Four-letter genetic code** of DNA worked out.
1960s	**Gene-based** theories of evolution developed.
1968	Motoo Kimura proposes **neutral theory of evolution** (see left).
1976	Richard Dawkins publishes *The Selfish Gene*.
1977	Fred Sanger invents method for **sequencing DNA.**
2001	Human genome sequenced.
2004	Chimp genome sequenced and compared with human genome.

Are genes selfish?

Of course, genes cannot have their own motives. Dawkins's point was that selection acted on genes; bodies are, in a sense, nothing more than the receptacles by which genes are transmitted to future generations.

Are humans 'different' from the rest of the natural world? Can biological mechanisms explain all aspects of human biology or do we need to call upon special processes? For the answer, see...

ON THE WEB

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ONE BIG FAMILY

If you have an unusual surname, you are probably related to other people with the same name. Travel back farther in time, and your distant ancestors will link you with hundreds, thousands, perhaps millions of different people.

Go back 11 generations and you had more than 2000 ancestors; if each of them and all their descendants had two children, you would have more than a million living relatives (assuming no interbreeding).

Some estimates suggest that the most recent common ancestor of all humans alive today lived just a few thousand years ago.

Go back even farther, and your ancestors would begin to resemble apes, then small pig-like mammals, fish-like creatures hauling themselves around on sturdy limb-like fins, and so on back to the very first forms of life, from which all living things are thought to have evolved.

Everything that lives today, or has ever lived, is the member of the same big family.

Tree of life

Living things fall into three major divisions: Bacteria, Archaea and Eukarya.

The idea that all living things arose from a **common ancestor** has given rise to the analogy of the '**tree of life**'. The trunk represents this ancestor, major branches are the high-level taxonomic groups and the twigs are the individual species themselves.

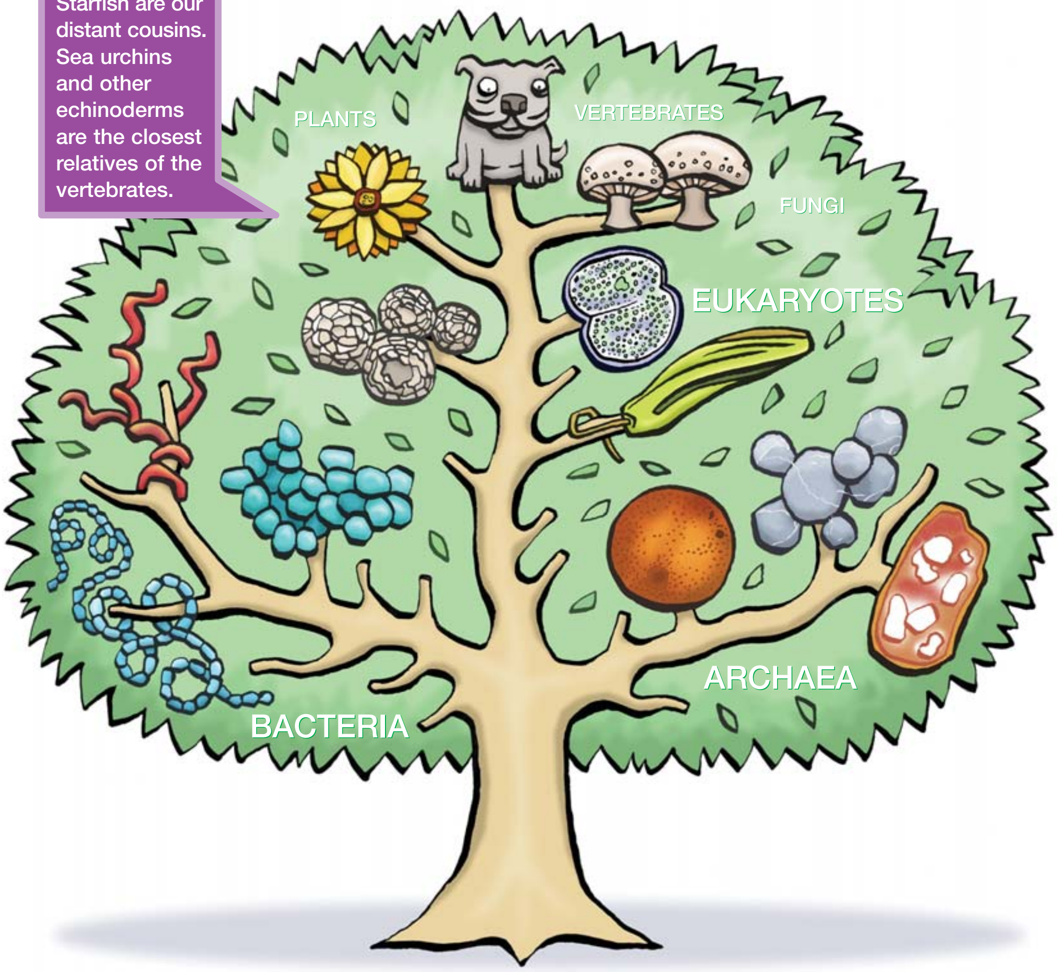
It used to be thought there were two main groups: the **prokaryotes** without a nucleus and the **eukaryotes** with a nucleus. The last two decades have seen this view significantly revised. A new group has emerged: the **Archaea. Although single-celled and lacking a nucleus, genetic comparisons suggest they are more closely related to eukaryotes than to bacteria**.

Because the vast majority of microbial life forms have not yet been grown in the lab, we know little about them. A new approach is to collect samples from particular environments – such as the sea or parts of the gut – and to sequence every genome within them.

These kinds of studies are revealing **incredible microbial diversity and new species never described before**.

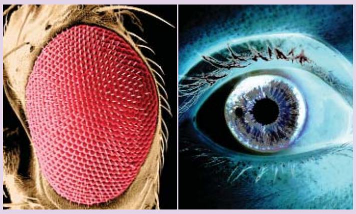
FAST FACT

Starfish are our distant cousins. Sea urchins and other echinoderms are the closest relatives of the vertebrates.



CONVERGENT EVOLUTION

Evolution usually works by diversification, but sometimes a similar solution is arrived at by different routes – convergent evolution.



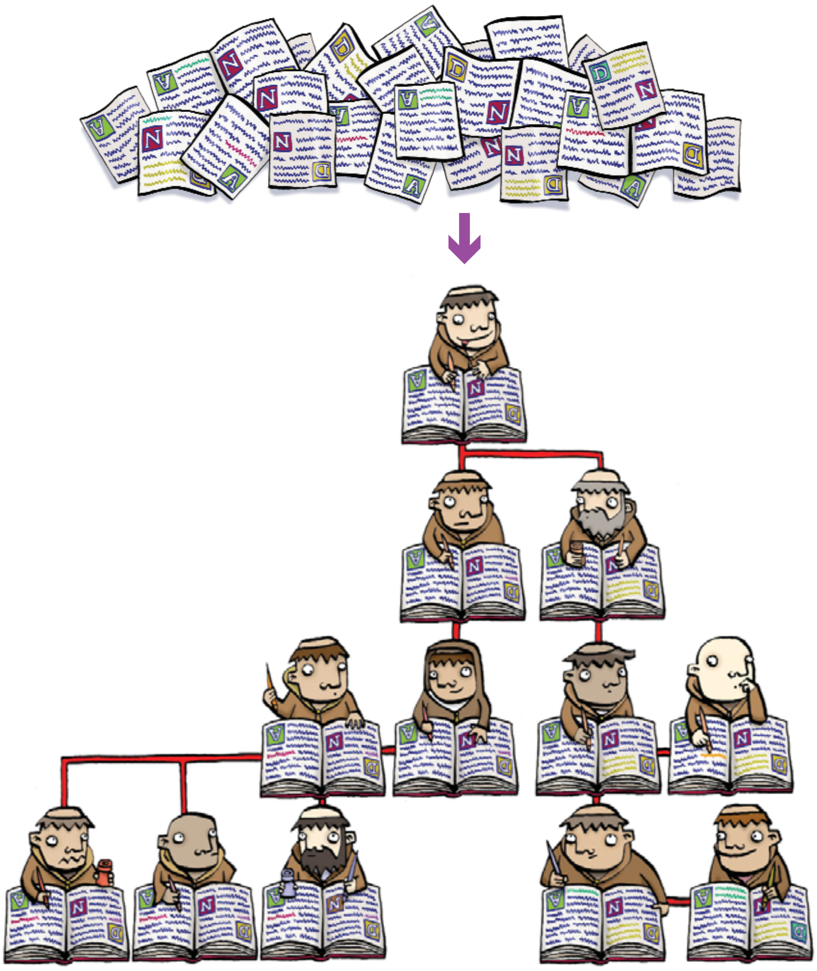
Oceans near the North and South Poles are a challenge to life. How do animals such as fish survive in temperatures around zero Celsius? Key to survival are **antifreeze proteins**, which stop ice crystals forming and destroying cells. Antifreeze proteins have been seen in fish from both the Arctic and the Antarctic – but the proteins are completely different.

Antifreeze proteins are an example of **convergent evolution.** An environmental challenge has been overcome in a similar way but independently in different species. **Wings** are another obvious example.

Eyes are an interesting contrast. The **compound eyes** of insects (above left) and **mammalian eyes** (above right) are completely different, but the eyes of **octopuses** and mammals are startlingly similar – even though they evolved independently.

It turns out that many of the same genes are used to build eyes in both octopuses and humans. Remarkably, many of these genes are also important in insect eye development – notably ***Pax-6***, which appears to be a '**master gene**' for building eyes.

This suggests that the common ancestor of all these organisms had a core set of genes involved in light detection. Over time, this core set has been added to and trimmed in the different lineages, as animals developed better ways of seeing their external world.



Building family trees

DNA sequence analysis is now used to build family trees.

It is fairly obvious that, say, rooks and crows are closely related. For many years, physical appearance was used to establish family relationships.

Now we know that genes are the units of inheritance, they are used to work out evolutionary relationships. Originally this was based on genes encoding **ribosomal RNA sequences**, as they are present in all living things. Now, many genes or even entire genomes can be compared.

From a collection of sequences, family relationships can be deduced. A useful analogy can be made with **manuscript copying** by monks in the Middle Ages.

Sometimes, monks would make a mistake. The next time the document was copied, the mistake was passed on. **By looking at which manuscripts contained which mistakes, researchers can trace the order in which they were produced** – the manuscripts' family tree.

Essentially the same technique is used to draw up family relationships based on gene sequences. This can reveal the relationships between species. It can also provide valuable information about the evolution and spread of viruses.

ON THE WEB

WRITTEN IN STONE: This newly discovered fossil animal, *Tiktaalik* (right), around 380 million years old, is an intermediate between fish and land-living reptiles. With many remarkable new findings, we could be entering a 'golden age' of fossil analysis. See more at Big Picture on Evolution online.

Beth Rooney, University of Chicago

CLOSE COUSINS: Comparisons between the human and chimp genomes are telling us much about the genes that make us what we are. These include genes controlling brain size and our reproduction – but also our muscles. Find out why a change in a muscle protein was so crucial at...

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Whose gene is it anyway?

Genes are widely shared but become adapted to take on new roles in different organisms.

To build a fruit fly, you need (among other things) a set of genes known as ***Hox* genes**. **These are 'master control' genes that coordinate the activity of many other genes**, so a head, abdomen, legs, antennae and all the other bits of a fly are built in the right place.

You need essentially the same genes to build a cockroach. Or a bumblebee, a frog, a mouse or a human being. ***Hox* genes are found throughout the animal world.** As new animals have evolved, their number and roles have changed slightly but they still perform basically the same function.

There are many ways in which genes can take on new functions. The classical way is by **mutation**, a change in DNA sequence altering the properties of the protein (or RNA) that it codes for. But mutation does not necessarily change the protein (or RNA); **if it affects control regions, the protein may be made in a different place in the body or at a different time during an organism's life.** A slight difference in a **control region** of the **insulin** gene, say, may affect our chances of developing type 1 diabetes.

Sometimes genes or collections of genes (or even entire genomes) are **duplicated**. The vertebrate *Hox* genes, for example, come in four clusters, duplications of a single original group. **Following duplication, genes can be free to take on new functions**, as one gene can continue to perform its original role.

Loss of gene function does not necessarily mean that the gene disappears from the genome. Genes may become inactivated but remain in the genome as **pseudogenes**.

The human genome contains a staggering number of pseudogenes, almost as many as 'real' genes. Among these are genes that, in mice, make a tail.

For more on the many ways in which variation in DNA is created, see Big Picture on Evolution Online.

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LEGLESS: Snakes have lost leg-making *Hox* genes during evolution. *Hox* gene clusters in different animals look different, depending on how species have evolved.

iStockphoto

NO SWEET TOOTH: Cats are indifferent to sweet things because they cannot taste sugar – a gene coding for part of the sugar receptor is a pseudogene.

EVOLUTION IN ACTION

FAST FACT
Analysis of DNA from museum specimens revealed that the dodo is a type of pigeon.

Evolutionary change generally takes place over long time periods. It is, therefore, rare to see it in progress. More usually, likely time courses of change are inferred, for example from fossil records or analysis of genetic changes.

Occasionally, though, evolution is so rapid we can see it happening before our eyes.

Speciation

Darwin called his book *On the Origin of Species*, but what exactly does the origin of species mean? How is a species formed?

A species is a group of animals or plants that are able to interbreed.

A new species is formed when two populations of animals or plants accumulate so many different **genetic changes** that they cannot interbreed and produce fertile offspring.

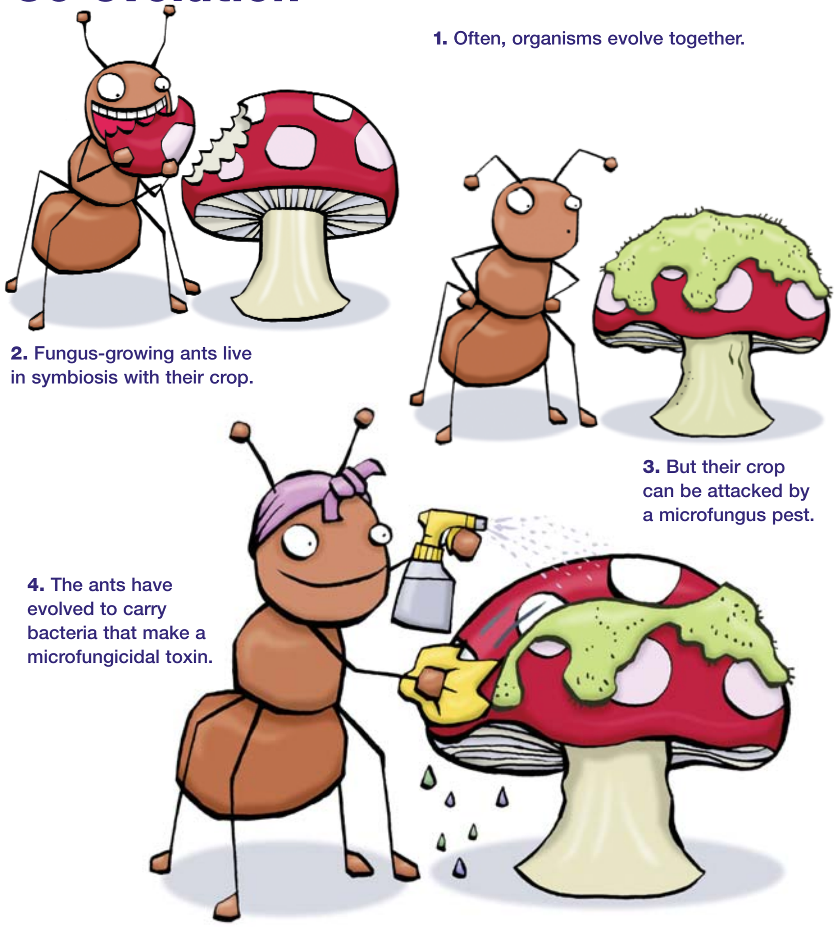
Typically this happens when two populations become geographically separated – when continents move, or a river changes course or a mountain range appears. Sometimes plants and animals become isolated on **islands** or in **lakes** and will begin to diverge.

Inter-species crosses mostly generate no viable offspring, because of chromosomal or genetic incompatibilities. Even if offspring are produced, they are usually infertile – like the mule.

But how did those incompatibilities appear in the first place? In fact, even simple genetic changes can create reproductive barriers. Recently, experiments on closely related species have revealed specific genes that cause reproductive isolation.

Typically, such genes affect reproductive biology (usually in males) and are under selective pressures. Male sterility in two species of fruit fly and mice has been pinned down to simple genetic changes.

Co-evolution



ARE HUMANS STILL EVOLVING?

Are human beings still subject to natural selection?

The minuscule doors of medieval houses suggest that people were shorter then than they are now. We do seem to be getting taller – but that's due to better diet rather than any evolutionary change.

With most people now surviving to reproductive age (at least in rich countries), have selective pressures been completely eliminated? Birth weight – mainly governed by genes – used to be strongly associated with neonatal survival, but given the advances in healthcare of newborns, it is now only weakly related to risk of death.

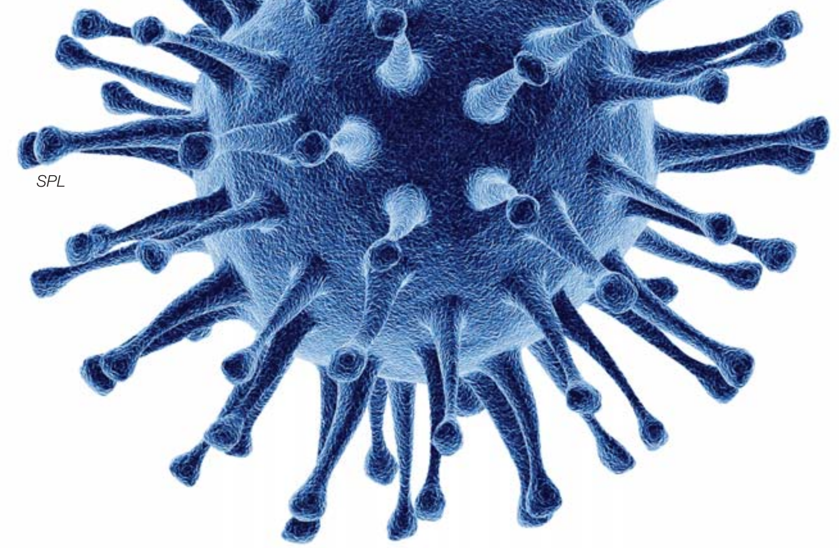
Direct evidence would be changes in the frequency of particular alleles over time. As evolution is usually a slow process, it is difficult to see it taking place directly. There is some evidence that selection for resistance to **HIV** is altering the make-up of populations in Africa. Selection is acting on the **major histocompatibility complex**, a large set of genes involved in defence against infections.

But we can also use **indirect methods.** One is to compare our genomes with those of our relatives, such as chimps, and to find examples of genes under **positive selection**.

Another approach is to map the **geographic distribution** of particular alleles. Sometimes alleles can be seen gradually spreading outwards from a source. For example, an allele that increases **women's fertility** very slightly seems to be spreading southwards from northern Europe.

So despite our best efforts, we have not yet outwitted evolution.

FAST FACT
Mus spretus and *Mus domesticus* look similar, but crosses between these two species of mouse fail to produce offspring, because of a single genetic incompatibility.



SPL

Pathogen evolution

Organisms that cause disease illustrate the power of evolution.

Bacteria, single-cell pathogens, have one huge advantage in the evolutionary game. While it takes the average human about 25 years to reproduce, bacteria can do it in minutes. So a chance change, which gives a bacterium just a tiny advantage, can rapidly spread.

The classic example of this is **antibiotic resistance**. **Antibiotics exert enormous selective pressures**. If, by chance, a mutant appears that can tolerate an antibiotic, it is at a huge advantage.

Now, because of our lax use of antibiotics, resistant microbes are a big problem. Use of antibiotics when they are not needed (e.g. for viral infections) and in agriculture (they are widely used as animal growth promoters), and a tendency for people not to stick to dosages prescribed, creates a situation where low levels of drug exist. **Partially resistant bacteria have a survival advantage and spread**. Now, **MRSA**, **multidrug-resistant TB** and other drug-resistant bacteria are a major threat worldwide.

Hijacking the cell

Viruses, tiny particles that infect and take over a cell, also have numbers on their side. A single infected cell can spew out millions of new virus particles. Once again it is **diversity** that underpins their success. In most organisms, heritable material such as DNA is copied extremely carefully. **In many viruses, though, genome copying is extraordinarily haphazard**. But with millions of copies produced in each cell, plenty will be fine – and among the millions of 'defective' ones there may be some promoting drug resistance.

This is one reason why **HIV** is so dangerous and **flu** is so difficult to treat. They are **moving targets**: no sooner has the immune system learned to recognise one form than it has changed into something else.

Mixing pots

Virus genomes can also swap bits of their genome with one another. This may create defective viruses, but occasionally something with brand new powers can arise. This is probably how the **Spanish flu** epidemic of 1918 began. An avian flu virus mixed with a human flu virus, possibly in a pig (pigs can be infected by both avian and human strains of flu). This new virus could infect and be spread between people, and was lethal.

This could happen again, with **avian flu strain H5N1** (above). **Currently, this strain can be spread from birds to people but not between people**. But if it swaps genes with another virus and becomes transmissible between people, the potential for a global pandemic is very real.

A QUESTION OF BALANCE: Why are harmful alleles, such as that causing sickle-cell disease, not eliminated by natural selection? Although two copies of the allele are bad for you, one copy protects against malaria, and is selected for in places affected by malaria. So the allele is maintained by 'balancing selection'. Selective pressures on genes are often subtle and dependent on context. See more at...

ON THE WEB

www.wellcome.ac.uk/bigpicture/evolution

Juan G Montañés (photography) and Mauricio Linares (production)

FLUTTER BY: Speciation usually results from the splitting of a single lineage, but sometimes two species may fuse to create a third. *Heliconius heurippa* (left), for example, appears to be a hybrid of *H. melpomene* (top right) and *H. cydno* (bottom right). Interestingly, mate preferences maintain the three separate species: males only go for wing patterns characteristic of their own species.

SEEING EVOLUTION

It is possible to see evolution in action – often because of human interventions.

Evolution is generally a **slow** process. Mutations are usually rare and selective pressures often subtle. But there are cases of **multicellular organisms** evolving rapidly.

Usually, these changes are linked to some kind of **human activity**, which has drastically altered selection pressures. Use of **pesticides**, for example, has seen the emergence of **insecticide-resistant mosquitoes**.

Deliberate or accidental introduction of animals has a big impact.

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Cane toads, introduced into Australia to control a beetle pest in the 1930s, are spreading rapidly through the country. Interestingly, they are themselves evolving: animals at the front of the invasion, those spreading fastest, have longer legs than those towards the rear.

ANTphoto

Cane toads are poisonous, but toad-eating **Australian red-bellied black snakes** have evolved resistance to their toxins (and are also less likely to eat them) in toad-infested areas.

On the US Atlantic coast in the 1800s, **mussels** faced an influx of **European shore crabs** brought across by traders. Over time, mussels appeared that could detect a chemical released by the crabs and, in response, reinforced their shells. Then, in 1988, a new invader appeared: an **Asian crab**, which did not produce the chemical released by European crabs. Now, where European and Asian crabs exist, the mussels reinforce their shells in response to both species – they have evolved to detect the new invaders. In places still free of Asian crabs, mussels respond only to the Europeans. So mussels have undergone a significant evolutionary change in less than 20 years.

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UNANSWERED QUESTIONS

Although the general principles of evolutionary change are widely accepted, many details remain to be worked out.

This is hardly surprising: evolution covers a wide range of subjects, from the molecular biology of genes and proteins to the interaction of populations on a global scale.

We have much still to learn about life's history on Earth – and how it all started.

SEX

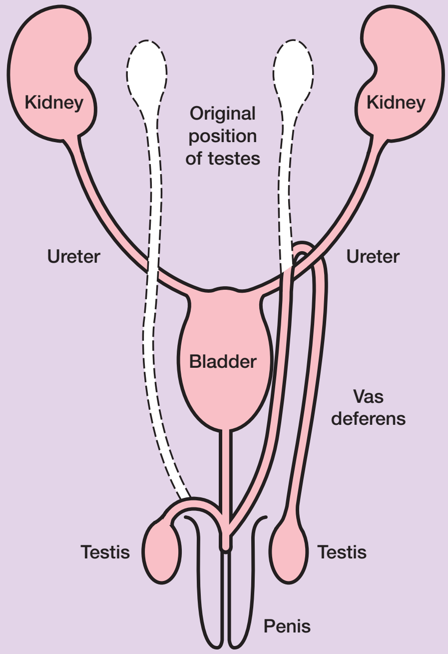
Sex creates problems for evolutionary theory. Asexual reproduction is much more efficient – for one thing, you pass on all your genes, not half of them – so should out-compete sexual reproduction. Yet many organisms need sex to survive. The answer appears to lie in the long-term gains sex provides, by shuffling genomes. This was covered in *Big Picture on Sex and Gender*.

DESIGN FLAWS

Our bodies are far from perfect – and evolution is to blame.

Anyone who has endured the pain of childbirth will surely query the concept of a skilled designer. There are other examples where, if the human body has been designed, it has been botched. We seem to have too many teeth for our jaws, for example – probably because jaw size has slimmed down during evolution as our skulls have grown.

Another example is the tube linking the mammalian testis to the penis (the vas deferens), which loops up and over the ureter – a bizarre and seemingly pointless detour. The solution to the riddle lies in the early ancestors of mammals, which had testes inside the body. As they descended during evolution, they could have gone behind or in front of the ureter. By chance, they went behind, so the vas deferens has to loop up and over, gradually lengthening as the testes descended.



FAST FACT

Losing a gene can be a good thing. A mutated *caspase-12* gene has been selected for during human history; it may make us less likely to suffer from sepsis.

Origins of life

It's the biggest question of all: how did life get going?

There has been life on Earth for about 3.5 billion years. Once it began, evolutionary processes could shape its future. But they need something to work on. **Although there are several possible ideas, the origin of life remains an area of uncertainty**.

SPL

One of the most famous contenders is the '**primordial soup**' model. This is well illustrated by Stanley Miller's famous experiment in the 1950s, where he mixed some simple chemicals, applied a strong charge, and stood well back. Lo and behold, he managed to create complex 'biological' compounds such as amino acids.

Unfortunately, there are big problems with this model. For a start, **the conditions Miller mimicked in the lab were unlike those now thought to exist at the dawn of life on Earth**. And 'life' is more than just making a few complex molecules.

There are at least two key aspects to life:

- the ability to carry out **controlled chemical reactions** (metabolism)
- the ability to **store and pass on information** (e.g. in DNA).

With these powers, **self-replication** is possible, so a chemical entity can continue to make copies of itself.

But there is a chicken-and-egg issue here. Metabolism usually depends on proteins. Yet the information to make proteins is stored in DNA. So which came first, proteins or DNA?

A possible solution could be DNA's cousin, **RNA**, which can both store information (e.g. some virus genomes are made of RNA) and catalyse chemical reactions. Many believe that there was once an **RNA world**, populated by self-replicating RNA molecules.

But where did these molecules come from? Some propose a variant of the primordial soup model, in which pools of chemical broth became highly concentrated, allowing unusual chemical reactions to take place.

British geologist Graham Cairns-Smith thinks that **clays** may have been important, because of their self-organising properties.

A popular new idea is that life emerged at hydrothermal vents – extraordinary geological and biological structures deep on the ocean floor (left) where energy from inside the planet is released into the seas. There are home to highly unusual organisms, carrying out odd chemical reactions.

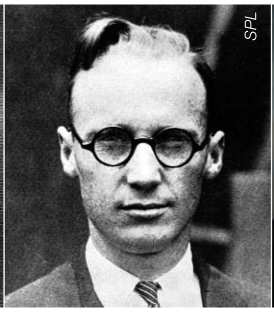
Finally, some believe that the idea that life arose spontaneously on Earth is so fantastic that it could not have happened. Perhaps life was 'seeded' on Earth, brought in on **meteorites**. But then, where did those life forms come from…?

Did the designer do it?

Some people find the idea that natural processes alone created complex life too far-fetched. They prefer a model in which an unspecified ‘designer’ has had a hand.

Wherever one looks in biology, there is **complexity**. Often, the relationships between molecules or organisms – such as plants and the animals that fertilise them – look so well made that it is tempting to believe they were created that way.

This is the thinking that inspired **William Paley** (below left) in the 19th century. He used the analogy of a **watch** found lying on the ground. The coordinated function of all its parts, suggested Paley, implied that it must have been designed. Where there was a watch, there had to be a **watchmaker**.



SPL

US Federal Government

Creationism is a **faith-based position** that holds that life/people were created by **God**. At its most extreme is the belief that the world was created literally as described in a holy book such as the Bible or Qur’an.

Creation science was a move to position this kind of thinking as legitimate science. It attempted to portray evolutionary thinking as incomplete and flawed, with creation-based versions a viable alternative explanation.

Intelligent design (ID) attempts to raise the same issues but without including a religious dimension by not specifically saying that God is the intelligent designer.

Much the same line of thinking underpins the ‘**intelligent design**’ (ID) idea. It holds that some biological structures are so complex and integrated, functioning in a way that depends on the whole structure – the **bacterial flagellum** is one example used – that they could not possibly have evolved bit by bit. This property is known as **irreducible complexity**.

This act of creation was the work of an ‘intelligent designer’. The nature of this designer is not specified, but there are not many candidates other than God.

The history of ID

ID is the latest version of a strand of thinking that began with **creationism** before moving on to **creation science** and then **ID**. It has particularly vocal supporters in the USA.

Monkeys and men

The battleground for these arguments has mostly been the US education system. Two landmark events stand out: the so-called **Scopes Monkey Trial** of 1925 and the **Dover Area School Board** case of 2005.

John Scopes (above centre) was a high-school teacher convicted of illegally teaching evolution in Tennessee.
See **www.wellcome.ac.uk/bigpicture/evolution** for his full story.

The 2005 case was based on the Dover Area School Board’s attempt to introduce ID into local schools, by insisting that teachers read a statement that evolution was not established fact and that ID was an alternative theory.

Supporters of evolution challenged this policy on the grounds that ID was simply creationism in disguise and, under the US Constitution, religion cannot be taught in science classes. Pro-ID campaigners attempted to show that evolution was a flawed theory and that some scientists supported ID.

The case was notable for featuring an independent ‘referee’ – Judge John Jones (above right) – commenting on ID’s scientific credentials, having heard from both sides. Judge Jones demolished the arguments of ID campaigners, arguing that “ID cannot uncouple itself from its creationist, and thus religious, antecedents”.

His judgment made it clear that ID could not be considered a valid scientific theory.

Brains and behaviour

Can evolutionary ideas explain human behaviour?

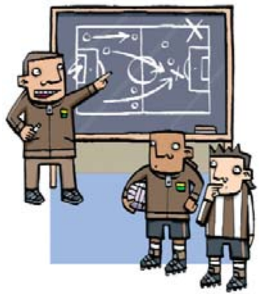
Darwinian views of evolution imply that all aspects of the biology of organisms must be **adaptive** – providing some kind of selective advantage – otherwise they could not have evolved. Applied to humans and their behaviour, this is known as **evolutionary psychology**.

The case of humans is special for several reasons. The first **is the radical change in the way we live over the past few thousand years** – a blink of an eye in evolutionary terms. Then there is the power of our **brain**, about which we know relatively little. Finally, there is the potential for **cultural evolution** (see page 3).

Evolutionary psychologists suggest that humans are adapted to survival in a harsh, stone-age world. Our brains have given us such a competitive edge that we have spread across the globe and developed art, culture and technology at remarkable speed, but deep down **we are driven by the same survival instincts we had in those early days on the African savannah**.

Selective pressures shaping our **vision**, **hearing** and **memory** are relatively non-controversial. For example, **we remember fearful incidents better than run-of-the-mill events** – which would help us avoid danger.

But what about, say, our reaction to **strangers**? **Are we programmed by evolution to find them threatening?** Or is this a reaction driven by the nature of modern society?



Could some skills simply be by-products of an adaptive trait? The Chinese excel at **table tennis**, but no one seriously believes that table tennis ability promoted survival in the Pleistocene or that there are genes for table tennis.

So evolutionary thinking can undoubtedly help us understand how the human mind has developed. But though it can come up with plausible explanations for human physiology or biology, these are hard to test experimentally. And, of course, the links between genes and human behaviour are rarely straightforward.

BUT WHAT ABOUT…

- **How did life arise?**
- **Why is sexual reproduction so common?**
- **How does cooperative behaviour arise?**
- **Does evolution proceed in small steps or in sudden bursts?**
- **How are new species formed in the absence of physical separation?**
- **What are the genetic mechanisms that lead to speciation?**
- **If genetic changes usually lower fitness, how do new species accumulate a range of changes that, collectively, enhance fitness?**

Although definitive answers are not known for these and other questions, there are many plausible theories that are being explored.

SOCIAL IMPACT

***On the Origin of Species* rocked Victorian society. At the time, Britain was to a large extent ruled by a religious elite. Evolutionary thinking called into question this theological power base – science could come up with answers as well as religion.**

On the other hand, evolutionary thinking – and how it was promoted – was also shaped by the nature of Victorian society, including the belief in the inevitability of 'progress'.

Darwinism was also enthusiastically taken up by others, and sometimes used in ways that would have horrified Darwin himself.

Charles Darwin, 1871.

In Darwin's day

Charles Darwin may be the name associated with evolution, but he was not alone in his radical thinking.

Much is made of Darwin's voyages on *HMS Beagle*, and his encounters with Galápagos finches. **Yet his theory of natural selection was not an inspired bolt from the blue.** Other people had been thinking along similar lines.

In the 1840s, **Robert Chambers**, a publisher from Edinburgh, had caused ripples with his anonymous work, *Vestiges of the Natural History of Creation*, which championed evolutionary thinking in geology. And, of course, **Alfred Russel Wallace** came up with essentially the same idea as Darwin.

Wallace outlined his theory in a letter to Darwin. Darwin feared being scooped, but also did not want to cheat Wallace. He consulted eminent friends, who suggested that **he outline his theories at a special meeting of the Linnean Society, along with a paper from Wallace.** Darwin then set about describing all his evidence, which he published in *On the Origin of Species* in 1859.

This book was truly revolutionary. Darwin himself was retiring and promoted his thinking mainly through letter-writing. It was people such as T H Huxley, often called 'Darwin's bulldog', who fought his battles in public.

Huxley took part in evolution's most famous confrontation, with outspoken critic of evolution **Bishop Samuel Wilberforce** at the British Association for the Advancement of Science annual meeting in Oxford in 1860. **Wilberforce enquired whether Huxley was descended from apes on his mother's or father's side.** Amid uproar, Huxley retorted that he would rather be descended from an ape than a human who used "great gifts to obscure the truth".

Huxley was not driven solely by a belief in 'truth'. He was an academic outsider, and wanted to establish his career in academia. Bishops held a stranglehold on learning, power that Huxley was keen to demolish.

Another important figure was **Herbert Spencer**. He was interested in people and **society**, and held that **societies evolved towards 'higher' civilisations in a natural, organic way.** He drew upon Darwin's thinking to support his own ideas. It was Spencer who coined the phrase '**survival of the fittest**', which Darwin slipped into later editions of his own book. **The application of Darwinian thinking to social affairs has always been controversial** (see below).

Darwin's book was a product of its time. (Interestingly, it was also helped by advances in **printing technology**, which brought books to a wider audience.) It captured, and built on, existing thinking, and reflected a Victorian obsession with progress and the march of civilisation. Even so, it remains one of the most important books ever written.

SOCIAL DARWINISM

Natural selection operates in a biological context. Others have applied it to the way people and society behave – often with disastrous consequences.

Darwin's is an unflinching view of the world: natural selection only works because the ill-adapted cannot compete and so die off. It is not the strong that are selected but the weak that are eliminated.

Darwin made no claims that natural selection could be applied to human society – but others did, including Herbert Spencer. This idea of social Darwinism was popular in the late 19th century. Social conservatives liked the idea as it could be used to support social inequalities – survival of the fittest was the natural order.

It also captured the idea of inevitable social progress. Just as humans were the pinnacle of evolution, so civilised society was the top of human endeavour.

But this was not the only application of evolutionary thinking to humans and human society. Because of the harsher climate, humans from the north were thought to be subject to stronger selection pressures, and so were fitter than those from tropical regions. Ideas of racial superiority were common.

So too was the belief that society depended on the quality of its population. Reproduction of 'low-grade' people – the 'feeble-minded' or infirm – was thought to be damaging to a nation in a competitive world.

In response, the eugenic movement promoted the idea of selective breeding to preserve and enhance society. Eugenic ideas were common and largely respectable in the early part of the 20th century. They were taken to the extreme

One for all, all for one?

If natural selection favours survival of the fittest, and genes are selfish, why do we ever help one another?

In the parable of the Good Samaritan, a man is robbed and left by the side of a road. Two travellers pass by on the other side but a Samaritan stops and offers help.

The parable illustrates the human ideal of **altruism** – helping others without expecting any benefit in return. **But if our genes are only interested in making more copies of themselves, why would they cause us to behave like this?** Why would natural selection favour people who helped others rather than people who looked after only themselves?

An early influential idea was that animals preferentially help their **relatives**, who share some of their genes. **The more closely related they are, the more likely they would be to collaborate**.

Kin selection suggested that genes supporting the survival of relatives could be favoured even if they imposed a personal survival disadvantage. As J B S Haldane put it:

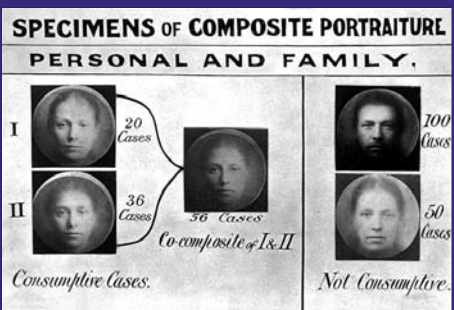
"I'D LAY DOWN MY LIFE FOR TWO BROTHERS OR EIGHT COUSINS."

And there is evidence in nature that animals' altruism varies with relatedness.

But kin selection cannot be the complete story. **Altruism, particularly in humans, goes beyond just family members**. What seems to be important is that **social coordination** and help for others is, in the long run, more successful. So mechanisms may evolve that lead to altruistic behaviour within a species because the long-term benefits outweigh the short-term advantage of selfishness.

by the Nazi Party in Germany during World War II.

Social Darwinism and eugenics are now widely discredited. This is due partly to the greater emphasis on individual freedom, and partly to a recognition that society is not shaped by forces outside our control: we decide for ourselves what kind of society we want.



ABOVE: Composite portraits by the eugenicist Francis Galton, 1883.

How might that work in humans? One line of thought is that of **'altruistic punishment' – that there are policers of cooperative behaviour that enforce fair play**. Anyone who transgresses a social norm is punished. This sort of behaviour can be seen in **game theory** studies, which explore people's altruistic or selfish decision-making in various scenarios.

Another approach is to use **mathematical models** to analyse the spread of genes assuming particular types of behaviour in a population. This has shown that strategies such as **indirect reciprocity** – 'I'll scratch your back because I know someone will scratch mine' – are successful.

Cooperation and altruism have been central to the success of human beings. They remain essential to coherent, stable societies today. Scientifically, why we started acting together remains only partly clear.

T H Huxley, by C Pellegrini, 1871.

Post-human world

***Homo technologicus*, *Homo modificasis* or *Homo survivor*? What does evolution have in store next for *Homo sapiens*?**

Life has existed for 3.5 billion years; humans for a few hundred thousand. If those 3.5bn years were compressed into 365 days, with life on Earth beginning at the start of 1 January, humans would appear in the closing hours of 31 December.

So it is early days in our evolution. We have removed many selective pressures, but are still evolving (see page 6). What will the next stage of intelligent life be?

Science-fiction writers have speculated endlessly about the emergence of **artificial intelligence**. We already have **genetic programs** – computer programs that learn as they go along. Along with developments such as **neural networks**, which simulate how neurons operate in the brain, and **fuzzy logic** (decision-making in the face of uncertainty, something else the brain is very good at), artificially intelligent systems are coming on in leaps and bounds. Whether or not they can 'think' is not clear – and may not even be a relevant question.

THE QUESTION OF WHETHER A COMPUTER CAN THINK IS NO MORE INTERESTING THAN THE QUESTION OF WHETHER A SUBMARINE CAN SWIM. Edsger Dijkstra

In most fiction, the artificially intelligent creations take over. The consensus is that the creation of genuine artificial intelligence would lead to profound social change.

Better humans

So what of people? One possible route might be **genetic enhancement**. It is theoretically feasible for us to alter the **germ line** (e.g. DNA in sperm or eggs), permanently changing our genome. Given the risks and the lack of a good reason to do it, germline modification is not yet done.

Another option is to use **technologies** to enhance the human capabilities. This would not change us permanently, but use of enhancements could become the norm, effectively changing the nature of humans.

Or the whole issue may be taken out of our hands. Some eminent scientists, such as Sir Martin Rees, the Astronomer Royal, believe that we have only a 50–50 chance of surviving this century.

Global climate change or some other **cataclysmic environmental event** – another supervolcano explosion perhaps – or even widespread human conflict could fundamentally change our environment. Who knows what factors would then be selected for?

REAL VOICES

The theory of evolution was first described in a Christian society. The debate between evolution and religion tends to focus on Christianity, but what of other belief systems? Here, people from Buddhist, Islamic and Sikh backgrounds share their thoughts.

Bryan Appleyard is Vice-President and Chairman of the Buddhist Society. He has been a Buddhist for more than 40 years.

Usamah Hasan is a Senior Lecturer in Computing Science at Middlesex University and an imam at Tawhid Mosque in east London. He is also a member of the Muslim Council of Britain.

Kanwaljit Kaur-Singh is Chair of the British Sikh Education Council and a member of many interfaith organisations. She has written several books on Sikhism, and contributes to radio and television on faith issues.

A Christian perspective, from *Big Picture* adviser Michael Reiss, can be found on the *Big Picture* website.

Do you think humans evolved from ape-like ancestors?

Bryan Appleyard Buddhism differs from the other major religions in that we don't believe in a creator, or a beginning.

Buddhism is based on the law of change and impermanence – that humans and the universe are in a constant state of flux – and evolution is inherent in that process. We have no opinion on whether we evolved from apes. There's no teaching of it, but equally no denial of it.

Usamah Hasan There's an ongoing debate in the Muslim world about that. Most traditional clerics resist the idea, because the texts say that Adam was the first human, which means he had no parents. If he had evolved from apes, he would have had two not-fully-human parents.

However, most Muslim scientists do accept some form of Darwinian evolution because of the experimental evidence. They interpret the texts to mean that Adam was the first man with the intellectual and spiritual faculties necessary to make him human.

Kanwaljit Kaur-Singh *The Guru Granth Sahib, the Sikh sacred book, says that only God knows when, how and why He created the universe and the life forms inhabiting it, including us humans. Our attempts to pin down the exact date and timing of the creation, and its mechanisms, are purely conjecture.*

Do you think other animals and plants have evolved from earlier forms?

KK-S *It's the same answer. Only God knows what He did – we are all just guessing.*

BA Yes that's a perfectly acceptable view. It's just not a teaching of Buddha.

How do you think life on Earth began?

BA Buddhists don't ask that question. Buddhists believe that there was no beginning and there will be no ending.

KK-S *The Guru Granth Sahib says that before the world began, there was utter darkness – a void. There was only God, and He was in abstract form, in a state of meditation. Then God manifested Himself. He created himself and the universe in His own time and at His own will. He is everywhere, inside and outside everything He created.*

What does your religion say about the origins of humans? How have scientific discoveries affected these beliefs?

KK-S *There's no contradiction with scientific discoveries. God created the world as it pleased Him and He's still creating it. Evolution is part and parcel of it.*

UH The Qur'an says that Adam was created from clay, which is a mixture of water and soil. Science fits with this: most of our bodies are made of water, and the clay theory of the origin of life suggests life began when complex organic molecules formed on clay crystals.

How do your religious beliefs influence your thinking about evolution?

UH God is a given, there is no doubt He exists. Because if God doesn't exist, why is there anything at all? You can't argue against God, no matter how much you find out about evolution.

KK-S *We believe that God is still creating the universe, so it's still evolving.*

How do you think scientific and religious thinking differ (if they do)?

UH From the seventh to the 17th century, the Muslims led the world in science and passed their knowledge to Europeans, so science is deeply embedded in the Muslim consciousness.

We believe that the role of science is to understand how God created the universe – and religion is about understanding the meaning behind it. We are told that God's nature is reflected in man, and that's why man has a spiritual role and responsibility in the world.

KK-S *Sikhs don't find any conflict with scientific theory. Scientists talk about the Big Bang. Likewise, the Guru says there was nothing, then God manifested Himself by creating the universe.*

As early as 500 years ago, the first Guru, Nanak, said there are millions of galaxies, stars and worlds, all of which may have their own civilisations, prophets and creeds. He also said that the planets stand where they are due to some divine law, which is the power that supports their weight. Both these beliefs have been borne out by science.

ABOVE: Buddha; Sikhs paying homage to Guru Nanak; passage from the Qur'an.

HOW DO YOUR RELIGIOUS BELIEFS INFLUENCE YOUR THINKING ABOUT EVOLUTION?

BA My religious beliefs don't go against evolution. I have no reason to doubt the origin of the species. Buddhists believe all life forms are constantly changing.

DO YOU THINK OTHER ANIMALS AND PLANTS HAVE EVOLVED FROM EARLIER FORMS?

UH Yes certainly. For Muslims, plants and animals evolving is not an issue. It is the idea of Adam having evolved from apes that is a bone of contention.

Religious thinking is about our job on Earth, which is to lead a good life – to earn honestly, not deprive or exploit others, and to serve God's humanity. In this way we purify our souls so that they can go back to God when we die.

BA Buddhism is similar to science in its analytical approach to life. Like a doctor, Buddha diagnosed the cause of our human problems in the Four Noble Truths, and offered a practical solution in the Noble Eightfold Path of Practice. Both the problem and the solution, are laid out 'scientifically', as formulas broken down into separate stages. There's no punishment or reward by a divine being. Simply, our intensified actions lead to favourable or unfavourable results.

The difference is that where science theorises about possible causes of the universe, such as the Big Bang, Buddhist insight about the nature of reality is based on direct personal experience. Buddha told us not to believe what he said, but to find out for ourselves.

Can science and religion coexist?

BA Yes. Religion and science take different routes to understanding the universe, but they meet at many points.

UH Yes, they did for centuries. In the early period Muslim scientists were devoutly religious. We believe everything comes from God, including our scientific intellect.

Does it matter if large numbers of people reject evolutionary theory?

UH It would be a problem if lots of people reject the idea of the sacred. It would also be a problem if people reject evolutionary theory based on blind fundamentalist belief in creationism. But if people reject it on the basis of evidence, that's not a problem. It is irrational religion and science that are problems.

BA No, it's entirely up to them.

This issue's classroom activity is based around different styles of scientific writing.

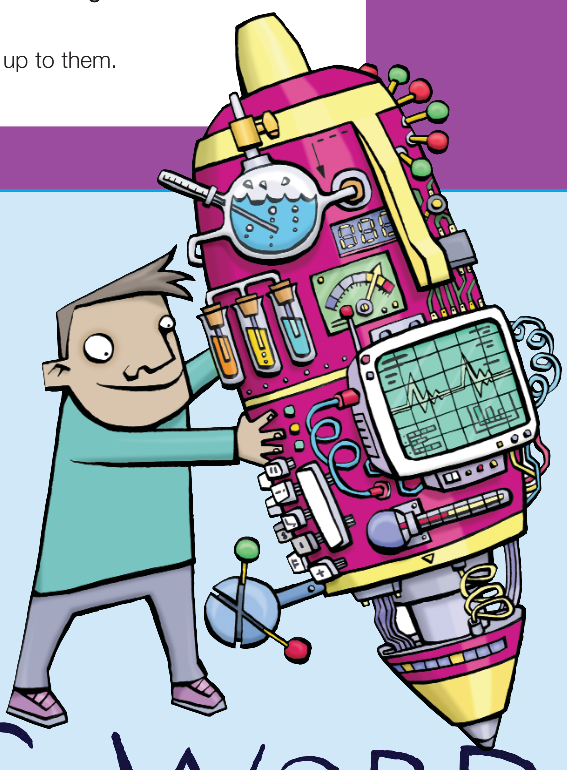
It gives pupils a chance to read, analyse and evaluate articles on evolution written in a variety of styles, including a scientific journal, a newspaper article, a web article and an exam question essay.

You have the opportunity to write your own piece in any of the styles and enter it in the Big Word competition being run by the Wellcome Trust in partnership with *New Scientist*.

Some great prizes are available, including the chance to have work published in *New Scientist*, an iPod Nano, £300 for your school science department and lots of other prizes.

Full details can be found at **www.wellcome.ac.uk/bigpicture/evolution**.

Deadline for competition entries is 30 March 2007.



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BIG WORD

EVIDENCE AND BELIEF

Does religion need proof of God's existence?

Is science capable of explaining everything?

What would convince a scientist of divine intervention?

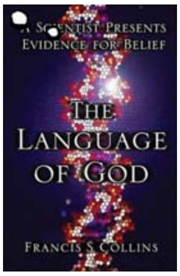
How many people question the reality of Newton's laws? Or special or general relativity? Quantum theory makes some scarcely believable predictions, such as particles being in two places at the same time.

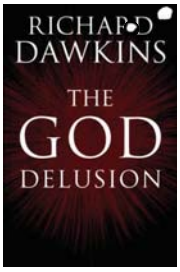
The evidence satisfies the specialists and that seems to be good enough for the rest of us.

But even though Darwinian evolution faces little or no academic challenge, polls highlight that a significant proportion of people do not accept its principles. Why should this be so?

Francis Collins led the Human Genome Project but believes in God.

Richard Dawkins is scathing of believers.





CONFLICT STUDIES: Trouble arises when religion challenges science on its own territory, or scientists attack religious thinking.

Darwin today

Nowadays, the theory of evolution satisfies most academics, though they argue over the finer details. The public is less convinced.

Almost no practising life scientist questions the general validity of evolutionary theory. But because the mechanisms are still being uncovered, **there is plenty of dispute about precisely how evolutionary change happens.** That is entirely to be expected and a sign of a healthy field.

Is science a faith?

Yet when a cross-section of Americans was asked, in a nationwide poll in 2005, **"Do you think human beings developed from earlier species or not?" more than half (54 per cent) said, "No"**.

The USA may be extreme – only Turkey has more evo-sceptics, according to an August 2006 study published in *Science*. In the UK, around 80 per cent of people are content with the idea that we evolved from earlier species, though that still means one in five is not convinced.

Why do so many people find the idea of evolution so hard to stomach? Is it a failure in **education**? There is some evidence that scepticism is higher among the less well educated in the USA, but plenty of highly intelligent people prefer to believe supernatural explanations.

Is it something to do with the **long odds** against life evolving by chance? **Astrophysicist Fred Hoyle likened it to the probability that a hurricane blowing through a scrapyard would produce a jumbo jet**. But that is a false analogy. It ignores the intermediate steps, the length of time over which evolution acts and, most crucially, the power of selection.

The key factor is **religious belief**. **Evolutionary explanations conflict with accounts given in sacred texts**. Some people can accommodate scientific explanations within their framework of belief; others cannot.

NATURAL SELECTION, ID AND CREATIONISM COMPARED

How well do intelligent design, creationism and natural selection compare as scientific theories?	CR	ID	NS
Is there evidence to support the theory?			
Is there evidence contradictory to the theory? If not, what would that evidence look like?			
Does the theory make predictions?			
Can the theory be tested?			

But it's only a theory

The theory of evolution shows how science operates.

There is an idealised view of the way science works. It starts with an observation and a question: our hypothesis. For example: When we make a loud noise spiders jump in the air, so do they hear through their legs?

Next we need to test the hypothesis with an experiment. If we cut off their legs, they no longer jump in response to noises. We triumphantly conclude that spiders do indeed hear through their legs and prepare our Nobel speech.

But it is possible that we may have overlooked something. Our conclusions are **provisional**. All current observations may be consistent with the theory, **but more experiments might force us to change our thinking.** Perhaps a bright spark points out that legless spiders wouldn't be able to jump even if they had heard a noise...

How has the theory of evolution stood up to scrutiny? Pretty well. It is theoretically possible that some new discovery will contradict it, but it hasn't happened yet…

Science and religion

Is conflict between science and religion inevitable?

Science is a way of looking at the world and coming up with explanations for why it is like it is. **The scientific method provides a route to gather evidence to choose between alternative explanations.**

Religions are based on **revelation** and **faith**. They too seek understanding, but by a different route: faith in the **truths revealed by higher authority.**

Science and religion have clashed in the past: Galileo with the Catholic Church, Huxley with Samuel Wilberforce. So are the two doomed to conflict? Opinions vary.

For a start, **people with religious beliefs take up very different positions.** Some people believe in the literal truth of a holy book such as the Bible, and therefore reject the theory of evolution as wrong.

Others suggest that sacred texts should be read more as **metaphors** or stories rather than as historical accounts. **Natural selection is the mechanism chosen by God to enact his vision for the world.**

What of scientists? **Some are content to see science and religion as occupying different spaces,** asking different questions in different ways. Science may answer the 'how' but does not touch upon the 'why'. Many scientists hold religious views – in fact, the proportion of 'believing' scientists hardly changed during the 20th century.

Other scientists argue **that there is no evidence for supernatural explanations,** and no need for God.

SCIENCE IN THE REAL WORLD

Science is logical and objective – mostly. But let's get real…

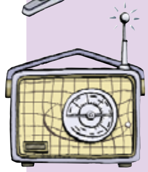
Hypothesis-test-revise is an idealised view of science. Like learning to drive, we all know what we should do, but after our test do we all drive perfectly?

Scientists are human too. The majority are honest, conscientious, hard-working and fair. Some, a tiny minority, cheat: they make things up, or fudge figures.

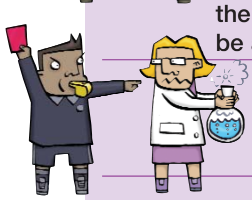
But scientists also tend to be attached to their own theories. They can be tempted to ignore a bit of data that doesn't fit. Occasionally, commercial interests may, directly or indirectly, cloud their judgement. There is always a natural desire to be proved right, and perhaps a tendency to look for evidence that supports a theory, rather than contradicts it. Sometimes, believe it or not, scientists make mistakes.

Should we disregard everything scientists say? Is all scientific knowledge tainted? In fact, unlike many other human activities, science has many safety checks.

PEER REVIEW
Scrutiny of research by other experts before findings are published.



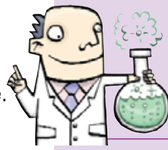
PRACTICAL INFORMATION
If a theory is correct, there may be ways to apply it practically. So quantum theory may be strange but it has given us transistors, and they all work. Conversely, the theories of inheritance developed by Trofim Lysenko in the Soviet Union were politically popular but proved to be a catastrophic failure in plant breeding programmes.



WHISTLE BLOWING
If researchers suspect foul play, they can raise their concerns with authorities.

REGULATION
Scientists are not free to do whatever they choose. There are many forms of regulation that they must abide by – from their employers (e.g. universities), ethical committees and national laws if, for example, they plan to use animals in their research.

PREDICTION
More fundamentally, a good scientific theory makes predictions. If the theory is true, then it will have other consequences. This brings us on to…



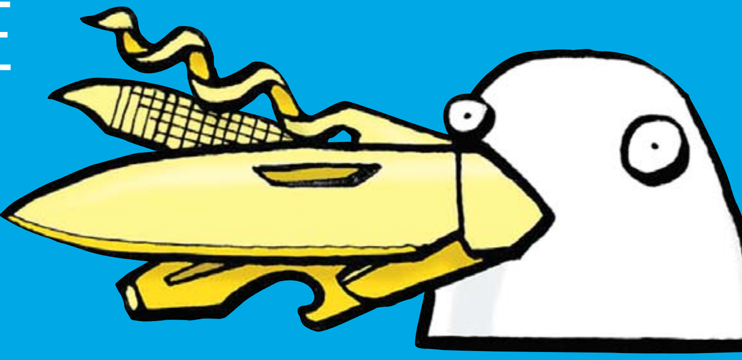
OBJECTIVITY
Experiments should be objective – another scientist should be able to carry out the same research in the same way and get the same findings. Which leads to…

REPLICATION
It is usually not enough for one group of scientists to report findings. These are often treated with caution, particularly if unexpected, until a second group has found the same thing.

TESTABILITY
A good scientific theory is testable. The results of experiments may support the theory, lead to its revision or overthrow it completely. If it cannot be tested, it is of little use in science.

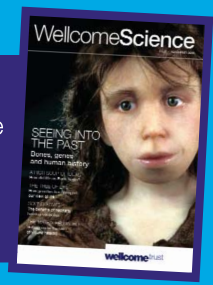
Scientists can be maddeningly cautious. But certainty only comes when 'new' science has stood the test of time. At early stages, uncertainty is the rule.

EVOLUTION:
THE BIG PICTURE



- According to **evolutionary theory**, all living things have developed from earlier forms of life over long periods of time.
- A key driving force is **natural selection**, by which organisms best suited to their environment produce more offspring than those less 'fit'.
- Evolution by natural selection was jointly proposed by **Charles Darwin** and **Alfred Russel Wallace** in the mid-19th century.
- The discovery of **genes** and **variation in DNA sequence** provided a mechanism by which natural selection can occur.
- **Genetic studies** and **DNA sequence comparisons** have provided considerable further evidence in support of evolution.
- The genetic make-up of species can also be shaped by random changes (**genetic drift**).
- Although the theory of evolution is often called **Darwinism** or 'Darwinian evolution', it has been greatly expanded and includes processes unknown to Darwin.
- The theory of evolution is **accepted** by nearly all practising scientists.
- The theory of evolution is **incomplete** – but that is the nature of scientific progress.
- An alternative model, **intelligent design**, has almost no support within the scientific community.
- A landmark court case in the USA in 2005 concluded that intelligent design was not a valid scientific approach but was being promoted for **religious ends**.
- The judge also concluded that calls to **'teach the controversy'** were misleading, as there is no scientific controversy.
- Conflict between **science** and **religion** is not inevitable: many scientists hold religious beliefs and many religious believers are comfortable with evolution.

Wellcome Science issue 4 includes articles on the origins of life, human evolution, the tree of life and whether humans are still evolving. *Wellcome Science* is available free – see **www.wellcome.ac.uk/wellcomescience**.



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