WHY DOES EVOLUTION MATTER?

CLASS 3: EVOLUTION IN SCIENCE AND TECHNOLOGY

"Nothing in biology makes sense except in the light of evolution." But what does such a sweeping claim mean, and how can we use the principles of evolution to understand other kinds of change? In this class we begin by looking at Darwinian evolution, and then turn to artificial intelligence. You'll have the chance to consider these topics in your own competition entries—and remember, top entries have the chance to win prizes!

Keep in mind you are not expected to read every class cover to cover: we've provided lots of links to further reading and extra material, but you are welcome to focus on what is most interesting to you!

SUBJECTS COVERED: Biology, Geography, Computer Science

RELEASE DATE: 4 November 2020

COMPETITION DEADLINE: 18 November 2020

IN THIS CLASS:

COMPETITIONS & PRIZES

We encourage you to participate in as many competitions as you can, but they are not compulsory. After the deadline for each competition, 2 winners will be awarded with Amazon vouchers and top entries will be published on *Inspire Digital*.

How to submit your entry:

- Complete your competition entry and make sure it follows the guidelines listed for that competition
- Fill out the *competition cover sheet*
- Email your entry and your cover sheet to us at *inspire@sjc.ox.ac.uk*

The deadline for all competition entries for Class 3 is **5pm on Wednesday 18 November 2020.**

COMPETITIONS:

inspire@sjc.ox.ac.uk

sjcinspire.com

Designed by Maren Fichter,
Inspire Project Support Officer

MAKING SENSE OF LIFE

"Nothing in biology makes sense except in the light of evolution." This was famously said by Theodore Dhobzhansky, one of the most eminent biologists of the 20th century, and practically every biologist in the world agrees with him. But what does such a sweeping claim mean?

SUBJECTS COVERED:
Biology

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What is it in particular about the living world that the theory of evolution explains? The answer is why the huge number of different kinds of animals, plants and microorganisms that are alive today exist at all, and what they are like. No one knows for sure how many species there really are, maybe 5 million but some think as much 30 million. Each one of these teeming species is unique. They range from bacteria that are a mere 100th of a millimetre long to the 100 ton blue whale; some species dwell 6,000 feet below the surface of the sea in trenches of near-boiling water. Some burrow in the sand of the hottest deserts, while others can fly 25,000 feet above the surface of the Earth. There are dwellers in high mountains, tundra and polar regions. Some microorganisms even live deep inside solid rock. The tropical rain forests on land, and the coral reefs in the sea are home to a seemingly endless variety.

The theory of evolution tells us that this amazing diversity is the result of gradual changes in organisms, generation by generation, from remote common ancestors to modern descendants, like a sort of family tree.

The theory of evolution explains the classification of the living world

As more and more species were discovered and studied, a very interesting thing about this vast diversity of organisms stood out. Species sharing a number of similar characteristics with one another can be put into a group. For example, the 5,500 species we call mammals are put into the group Mammalia because they all have hair, mammary glands producing milk to feed their young, warm blood, and many more similarities. Other species, such as frogs and newts, all have moist skin, broad heads, aquatic larvae and so on: they form a different group, called Amphibia. The birds, distinguished by their feathers, wings and beaks, are the group Aves. But it does not end there, because these groups can themselves be arranged into larger groups: amphibians, mammals, birds and a few others all have a spinal column, a brain enclosed in a bony skull, and four limbs. They form the group called Vertebrata. The Vertebrata in turn is distinct from, say, the Insecta which have six legs and fine breathing tubes, or the Mollusca with shell and gills. Going the other way, we find that groups can be divided into subgroups. The mammals are made up of 20 subgroups, such as the Carnivora for the dogs, cats, bears, etc., the Chiroptera for the bats, and the Primates for the monkeys, apes and humans. Each of these is then divided into even lower level groups still. In fact the entire living world is classified as groups within groups within groups within groups, all defined by their unique sets of characteristics. Such an arrangement is called a hierarchy.

The theory of evolution provides the answer to why the classification of life is hierarchical. A species divides into two new species, and each one changes a little bit by evolving new characteristics. Some of the new species go on to divide again, while others become extinct. As this process continues over time, the descendants come to differ more and more from one another in some of their characteristics. But they always share other characteristics that they inherited from their common ancestor. Species that diverged more recently have less differences from each other and make up the lower level groups. Groups of the lower level groups diverged further back in time and so have more differences from each other, and together make up higher level groups.

The theory of evolution explains adaptation

Every organism is adapted for its way of life. What this means is that the structure, the physiology, and the habits of each one are well suited to perform the processes of its particular life, however specialised that life is. Amongst the million examples we could mention are the wonderfully efficient design of the bird's wings for flying; the waterproof cuticle of an insect facing the dangers of desiccation; the protective spines of an acacia tree; the high crowns and ridges of the horse's tooth for grinding up tough vegetation; the dull green camouflage colour of a toad. The theory of evolution by natural selection, the great insight of two 19th century naturalists, Charles Darwin and Alfred Wallace, explains how such adaptations come about. The offspring of organisms always differ very slightly from one another due to accidental minor changes in their genes. If one is born whose difference happens to slightly improve how well it copes with the rigours of its existence, it is more likely that its siblings to survive. And if this new characteristic is inherited by its own offspring, it will be passed on to its descendants. In time, the improvement will spread throughout the breeding population as a whole, and the species will have become a little better adapted. Given enough time, which there is, a species will continue to adapt better and better to its environment.

In the one hundred and sixty odd years since the world was first introduced to the idea of evolution by natural selection, everything we have learned about genetics, ecology and palaeontology has added to our fundamental understanding of it.

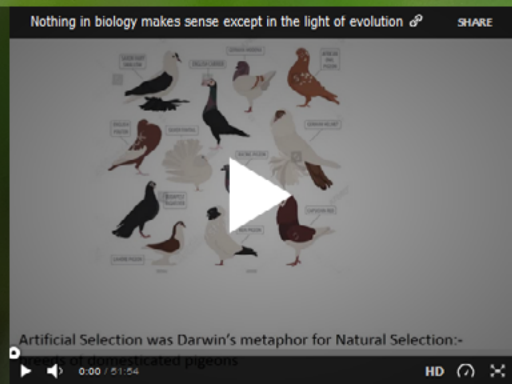
The theory of evolution is extremely wide-ranging

The theory of evolution by natural selection is associated in most people's minds with the diversity of the natural world, and the adaptations of living organisms. But it is actually a more general principle of how all sorts of things can improve over time. New variants, or experimental modifications of something are tested in some way. Those that prove to be better for their purpose are kept. Less effective ones are discarded. Centuries before Darwin, farmers knew how to improve the fat content of their pigs by only breeding from the fattest ones, or to increase the yield of their wheat by breeding from the ones with the largest heads. In fact this artificial selection, as it is called, was Darwin's main insight for his theory of natural selection. In more recent times, medical science has used the idea to help improve the treatment of diseases. Engineers often deliberately change a structure to see if it works better, and adopt the new version if it does so. The same principle applies to developing artificial intelligence by allowing a computer programme to improve its performance by trial and error, be it playing chess or diagnosing disease.

Dr Tom Kemp, Emeritus Research Fellow in Zoology
at St John's College

CHALLENGE YOURSELF...

If you're interested in exploring this subject further, you might want to take a look at Dr Kemp's virtual lecture on the same topic:



FOSSILS

Fossils record the history of life on Earth in rocks. But how can we learn about evolution, origination of new species and mass extinctions from fossils?

SUBJECTS COVERED: Geography

[*Click here to read this article on Inspire Digital!*]

Fossils are the remains of once living organisms that are preserved in the rocks formed from the mud or sand in which their dead bodies lay. In most fossils, only the hard parts are left, such as the spicules of sponges, the shells of molluscs and sea urchins, and the skeletons of vertebrates. Soft tissues are very occasionally preserved, for example where the animals were buried so suddenly that there was no time for them to be decomposed by microorganisms.

Fossils record the history of life on Earth

The fossil record is very incomplete, for it is estimated that only about 1% of all the species of animals and plants that ever lived have been found. But they do illustrate the broad outlines of the history of life on earth over the 3,500 million years since the first microorganisms. These were single-celled, bacteria-like organisms. Some, called stromatolites, formed onion-like layers of calcium carbonate. Others were preserved in silica solution which eventually formed flint. From about 2,000 million years ago, larger, more complex cells with a nucleus in the middle called eukaryotes are found. The next great step, around 1,000 million years ago, was the evolution of multicelled organisms. First there were fungi, algae and simple animals. Then, around 540 million years ago, a dramatic event called the Cambrian Explosion happened. This was the rapid appearance of fossils of all the main kinds of invertebrate groups: arthropods, molluscs, brachiopods, echinoderms and so on, and the earliest vertebrates.

The next revolution in life was the conquest of land, first by wingless insects, spiders and centipedes. These were soon followed by vertebrates, primitive amphibians that evolved from fish about 360 million years ago. They quickly spread over the land, giving rise to many new amphibians and reptiles, and eventually to the warm-blooded mammals and birds. Pre-humans and finally humans themselves commenced their evolutionary story away from ancestral ape-like primates about 5 million years ago.

Fossils show a continual pattern of origination and extinction

Evolution is usually thought of as the change of one species into another, and of course this how new species arise. But the great majority of species do not evolve but go extinct, and are replaced by new species that have already arisen. The nonstop pattern of extinctions and originations is called taxonomic turnover, and affects every level of classification. Species, as we have just seen, continually replace one another. Therefore groups of species do so as well, such as genera and families and right up to the highest levels. Each group arises, diversifies, and often declines before finally disappearing. The lesson is that, looked at over time, evolution is just as much a matter of extinction as of origination.

Fossils reveal mass extinction

The most dramatic discovery made thanks to the fossil record is called mass extinction. On average, about every 25 million years throughout life's history, a sudden, world-wide catastrophe caused the loss of a majority of the species, in seas and lakes and on land alike.

The greatest of mass extinction occurred 250 million years ago. It is called the end-Permian mass extinction, and over 90% of the living species were lost. The best known was the end-Cretaceous mass extinction, 66 million years ago, that saw the end of the dinosaurs. The 60% loss also included a great many species of other groups, such as the ammonites that had been thriving perfectly well until then.

The main cause of mass extinctions is probably huge volcanic activity, generating thousands of tonnes of carbon dioxide that heated up the world, and sulphur dioxide that created acid rain killing off land plants. The end-Cretaceous catastrophe is different from the others because it also coincided with a massive meteorite impact. If not the sole cause, it undoubtedly contributed greatly to the severity.

Dr Tom Kemp, Emeritus Research
Fellow in Zoology at
St John's College

FURTHER READING:

Timeline: The evolution of life on Earth

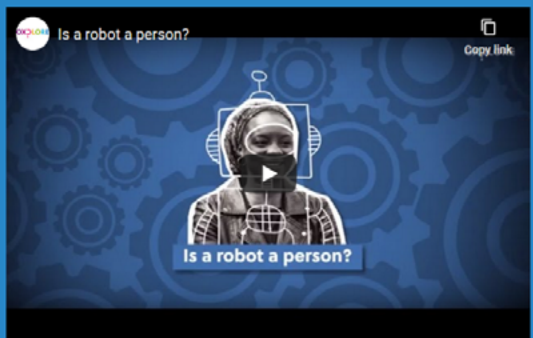
Patterns of evolution in the fossil record

The big five mass extinctions

Do we stay the same from birth?

We're born, we grow and develop over time but ultimately we stay the same person, right? Many factors shape who we are but what role does the mind, body and soul play in all this? And why do some people go on to commit crimes and cause harm? It's a tricky one... let's dig deeper...

Is a robot a person?



COMPETITION 5: THE FOSSIL RECORD

Palaeontologists believe that only about 1% of all the animals that ever lived have been found as fossils. How do they come up with this figure? Think about reasons why finding a fossil of a particular ancient species is so unlikely. You can also use the further reading suggestions in Dr Kemp's article to help you develop your answer. Your answer should be 300 words or less.

CLICK HERE TO SUBMIT YOUR ANSWER

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SUBJECTS COVERED: Computer Science

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IS YOUR COMPUTER MORE INTELLIGENT THAN YOU?

We have so far been looking at evolution from the perspective of Biology and Geology, but the principles of evolution can help us understand other kinds of change as well. For example, evolution can tell us a lot about how computers and artificial intelligence are developing now, and where they may be going in the future.

Over the course of billions of years, evolution has created many forms of intelligent life. Migrating birds and butterflies can find their way over thousands of miles. Pets know exactly how to play their owners for food and attention. And humans have built sophisticated tools and machines that compensate where we lack in physical ability and allow us to live almost anywhere in the world and even land on the moon.

All of this happened incrementally, with each new species and generation changing how they could behave in their environment. But thanks to recent advances in technology we can now create entirely artificial, intelligent systems that some fear may even prove dangerous to us as a species in a few decades' time. But how do we even know what intelligence is?

Imagine this: In 30 years you will be chosen to decide if we have truly developed a super-human artificial intelligence. Would an IQ test do? How would you decide if a work of art was created by a human or a robot? How would you know you are in a conversation with a human and not Siri? In many ways, deciding if an animal is intelligent is very similar to this problem. Would you agree that cats, dogs and dolphins are smart, but flies, fish and snails are not? Why? What behaviour do they show that is missing from today's computers?

Let us try to narrow this down a little bit and start with abilities that are super-human but which few people would call intelligent. For example, a computer can calculate 321 x 134 in a matter of milliseconds. Your phone can give you directions to almost any point in the world. And artificial neural networks can create shockingly realistic images of landscapes and people that do not exist (see links on page 8 below). The problems we can solve with these tools are arguably very complex and would take considerable amount of time and skill for humans to solve, but do not necessarily require intelligence. Similarly, the fact that birds can fly, fish can live in water, and leopards can run extremely fast does not make us think they are more intelligent than us, even though they can do things that humans cannot.

It gets a little more complicated when we look at some more recent advances in AI: The London-based company DeepMind has built AI systems that can beat even the best human players at difficult strategy games such as Chess, Go or the computer game StarCraft (see the video on page 8). This already comes a little closer to what we might require from an intelligent agent: to have the ability to act and react. Perhaps what we mean by intelligent behaviour is not any particularly high level of performance, but flexibility, goal-directedness and the ability to create something new out of old parts. This is what researchers call Artificial *General* Intelligence, or AGI. Arguably, we are still quite far away from achieving this.

This endeavour involves scientists from almost any discipline, for example computer science, psychology, neuroscience, philosophy or economics. You may be surprised to see psychology and neuroscience in this mix. They play an important role because they tackle some of the questions discussed above head on and try to understand how particular biological systems can be intelligent. Their insights can then be used to improve artificial systems. In fact, the co-founder and CEO of DeepMind, Demis Hassabis, holds a doctorate in cognitive neuroscience. Similarly, tools from AI have helped us better understand the human brain and the sophisticated behaviours it can produce.

Much ground-breaking work remains to be done – would you consider studying one of the disciplines involved? Which one?

Dr Keno Juchems, Junior Research Fellow in Psychology at St John's College

COMPETITION 6: ARTIFICIAL INTELLIGENCE

What could be the dangers and benefits of building an artificial general intelligence? How might such a system react if you want to unplug it? Write a 300-word essay in which you consider these questions.

CLICK HERE TO SUBMIT YOUR ANSWER

EXPLORE THE SUBJECT FURTHER...

When might we see an artificial general intelligence?

"*How to build a brain from scratch*": material of an Oxford Experimental Psychology undergraduate course by Prof Summerfield

Could you tell that a computer generated *these people* or *these artworks*?

St John's inspire programme
inspire@sjc.ox.ac.uk
sjcinspire.com
Designed by Maren Fichter, Inspire Project Support Officer