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To ensure you enjoy your visit

1. We invite you…

...to follow the trail through more than 3.5 billion years of the history of life on Earth in a superbly designed gallery built of glass and metal. No less than 600 fossils and 400 specimens in natural positions illustrate the six chapters of our new Evolution Gallery: Cambrian, Carboniferous, Devonian, Eocene, Jurassic and Present Day. Each stage will show you the often astonishing animals of each geological period as well as the most striking and educationally valuable examples of the evolution of groups of organisms, anatomical structure or animal behaviour. And we will include present-day examples, because evolution is a continuous phenomenon that can be observed around us. And don’t miss our “glimpse of the future” where we show what some animals might look like when evolution has run its course in another 50 million years or more!

Our gallery offers an opportunity to find out about the evidence of evolution, fossilised or modern traces of evolution, and the behind-the-scenes mechanics to this process which is inherent to life itself: mutations, unity and variability of living creatures, natural selection, genetic drift, the formation of species, etc. A satellite space is entirely devoted to the exploration of these processes.

And to round off your visit, in the Geode you can watch a short animated film entitled “Six Evolutionary Destinies”.

2. Educational Support

The staff of the museum’s educational service offer guided tours of the gallery and workshops on the theme of life and evolution.

“Evolution” guided tours
Chronological trail telling the story of life on Earth using some key stages and selected examples. The mechanisms of evolution are discussed with older members of the group if the teacher agrees.

• Target audience: from Primary 5 onwards
• Duration: 1 hour 15 minutes
• Maximum 15 pupils per guide

“History of Life” event
What is a fossil? Handling of fossils and placing them on a geological timeline. Causes and consequences of the great extinctions. Short guided tour of the Evolution Gallery.
Target audience: from Primary 5 to Secondary 6
Duration: 2 hours
Maximum 20 pupils per guide

“Evolution” event

• Target audience: Secondary 1 to 6
• Duration: 2 hours
• Maximum 20 pupils per guide

Documents
This teachers’ pack and questions to guide a self-guided visit can be downloaded from www.sciencesnaturelles.be/educa from March 2009 onwards.
3. Practical Information

Access

The Museum is located at 29 Rue Vautier, 1000 Brussels.
The unloading point for school buses is at 260, Chaussée de Wavre, 1050 Brussels.
The nearest railway station is Brussels-Luxembourg, a 5-10 minute walk from the Museum.
The nearest metro station is Maalbeek (line 1) or Trône (Line 2), both a 15-minute walk from the Museum.
The nearest bus stop is Museum (lines 34 and 80), a 2-minute walk from the Museum, or Parnasse (line 95), a 5-10-minute walk from the Museum.

Opening Hours

Tuesday to Friday: 9.30am to 4.45pm (10am to 6pm during the All Saints, Christmas, Carnival and Easter school holidays).
Saturday and Sunday: 10am to 6pm
Closed on Mondays and on 1 January, 1 May and 25 December.

Prices

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<th>For groups (minimum 15 people)</th>
<th>per person aged 2-25 years</th>
<th>adults over 25</th>
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<tr>
<td>Entry Museum</td>
<td>€ 3</td>
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One free accompanying adult per group of 15 people.
Free entry for teachers on presentation of professional credentials.

<table>
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<th>maximum 15 people per guide</th>
<th>per person aged 2-25 years</th>
<th>adults on weekdays</th>
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<td>Guided tour</td>
<td>€ 35</td>
<td>€ 62</td>
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<td>Animation</td>
<td>€ 3</td>
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Reservations

Prior reservations required for groups by telephone only +32 (0) 2 627 42 52

B-exursion train tickets

Groups can purchase B-exursion tickets which include a return train journey and entry to the Evolution Gallery at the Museum. (Quote reference n° 273, available at all staffed railway stations or by telephone +32 (0) 65 582 362 or by email to groups.national@b-rail.be). Note! To benefit from this special offer, you must reserve places at the Museum by telephone (+32 (0) 2 627 42 52) first, then contact Belgian Railways (SNCB).
The mechanisms of evolution
1. Where did life come from?
Geological discoveries appear to have established one fact: life first appeared on Earth 3,800 million years ago. When it comes to saying where and how, the theories diverge. The first organic molecules could have been the result of chemical reactions in tiny puddles or at the heart of the springs that became oceans. Or they could have fallen to Earth from space. There is a lot more to be discovered before we can understand how these molecules developed into living creatures.

2. The primordial soup
Many scientists believe that life began in shallow bodies of water. Ultra-violet light and lightening set off chemical reactions between different components of the primitive atmosphere, which produced organic molecules that dissolved in the water.

3. A clay mould
Rain loaded with organic molecules could have fallen onto clay whose heat made the water evaporate. The clay’s fine grains could have served as a substrate for the creation of longer molecules.

4. Origins in the abyss
Other scientists think that the cradle of life was in springs deep in abysses. The gases these springs gave off were rich in the elements required to make organic compounds. The great depth of these abysses would have offered protection from the very intense sunshine at the time.

5. Extra-terrestrial origins
Did life come from outer space? Perhaps. Of the twenty amino acids from which protein in living creatures is made, eight were first found in meteorites.

WORKSHOP

1. The chemistry of origins
Tiny organic molecules, dissolved in the primordial soup, bound themselves together into macromolecules, formed membranes and vesicles, and the first cell appeared. Much later, some cells acquired nuclei which protected genetic information. Then cells began to come together in colonies and pluricellular life had begun. Then some cells became specialised, binding together in tissues and forming organs. Now the rapid development of living creatures could begin.

Illustration
• Video-audio: life begins here

2. Pre-Cambrian Period
The first complex organisms, shaped like leaves or mattresses, were attached or anchored to the sea floor. Their morphology and fixation strategy suggests that they fed on plankton filtered from the seawater. Other organisms looked like modern-day molluscs, jellyfish and arthropods, but we do not yet know if they were related to these modern-day creatures. Their lack of shells or mouth parts suggest there were hardly any predators in their environment.
The strange animals of the Cambrian Period

At the beginning of the Cambrian Period, the Earth’s dry land was all grouped together in one super-continent. Gradually it split apart and separated and formed the continents we know today, with different climates. The super-continent’s climate was hotter than any modern-day climate on Earth.

1. Prelude to the Cambrian explosion

The story we are telling begins in the Cambrian Period, from which many astonishing creatures appear in fossil collections. But don’t be mistaken, complex organisms lived in the seas well before this period. However, with some notable exceptions, their soft-tissue bodies do not fossilise easily and so they have left very few remains.

2. Harder bodies

Even if, during the Pre-Cambrian Period, some organisms had mineralised shells, it was in the Cambrian Period that spines, shells and skeletons appeared. Most were made up of minerals discharged by cells to balance their concentration inside organisms: a sort of magnificent recycling! This hard tissue was a huge success because it contributed to supporting the animal by being an anchor point for its muscles and also helped to protect it from predators.

Sydneyia

Well protected by its carapace, Sydneyia was both a predator and a scavenger. This animal’s fossilised remains were found in the Burgess shale, a site discovered in 1909 and famous for containing extraordinarily well-preserved soft-tissue animals.

3. A liquid skeleton

We must avoid generalisations: all the animals of the Cambrian Period had not developed hard tissues, and there were many soft-tissue animals around at that time. Look at worms: they have no rigid supports and small liquid-filled sacs in each segment of their bodies act as a skeleton.

4. Prey and predators

Animals with sharper senses, more efficient organs of movement and multiple means of attack and defence bear witness to a world in which preying on other animals was increasing. And when predators develop new means of attack, natural selection will favour prey which develop adequate defences, and so on and so forth. This dynamic has been present throughout the history of life on Earth.
5. The bases of modern-day animals

In the profusion of animal forms of the Cambrian Period are all the large modern-day groups: arthropods, sponges, molluscs, worms and chordates. All of these groups had Cambrian ancestors who shared the same basic structure. Some strange, initially unclassifiable animals tell us a lot about the origins of the modern groups and their relationships with each other.

6. Our “great” ancestor

Here is Pikaia. The dark line running the length of its body appears to be a notochord, the precursor of our spinal column. It was considered to be the first chordate for many years, but its primacy was recently called into question by the discovery of Haikouichthys in a fossil bed in Cengjiang, which has the same characteristics but is from an earlier period.

7. Difficulties in classification

The strange structures of Wiwaxia, Ondothogriphus and Aysheaia make it difficult them to attach them to a known group. Some scientists have suggested that they belonged to phyla which disappeared, as if the Cambrian Period had experienced an experimental stage in the means of organisation, with some ending without descendants. We now know that Wiwaxia and Ondothogriphus were primitive molluscs and that Aysheaia was linked to the onychophora (velvet worms).

8. Growing specialisation

The organisms of the Cambrian Period bear witness to unprecedented anatomical and functional complexity. For example, take a crustacean such as Canadaspis. It had complex respiratory and movement organs: each of its feet was made up of two segments, of which one contained its gills. It had antennae, eyes and jawbones which enabled it to feed on organic particles and small prey.

9. A great classic

From the Cambrian Period onwards appeared animals that would become an unmissable presence in marine environments for 250 million years: trilobites. Characterised by three longitudinal lobes (from which their name is derived) trilobites were extraordinarily diverse. During their history, more than 18,000 different species have been recorded, of all shapes and sizes.

WORKSHOP 1– Attack and Defence

1. Recycling minerals

Changes in the climate and the composition of the oceans allowed some organisms to acquire hard tissue. The oceans were enriched with dissolved oxygen. Organisms which had the genetic tools required developed more complex metabolisms which allowed them to absorb and incorporate minerals into their hard tissue. Animals thus made beneficial use of an excess of the minerals that was not required for their bodies to function by stocking them outside their cells.
illustrations
• 5 enlarged 3D models of Cambrian Era animals
• Video & audio: Biomineralisation

2. The skeleton: a key feature

Many animals secreted skeletons in the form of shells, carapaces, plates or spines. Skeletons were made of chitin, an organic material which becomes rigid when combined with calcium phosphate or calcium carbonate. However, often the skeletons were completely mineral, made of silica (like the spines of a sponge) or calcium carbonate (aragonite and calcite shells of molluscs, aragonite in corals). These skeletons were used to support the animals’ bodies, to protect them and to help them move.

3. Advantages of a mineral skeleton

From the Cambrian Period onwards, arthropods, which were already in the majority, begin to display signs of carapaces. We have also found the fossilised remains of animals covered in spines and animals with shells. These structures appeared about the same time as predation began. Evolution could have favoured them because they offered protection against predators. In addition, limbs which allowed the animal to catch things, to cut them up or grate them aided their feeding.

illustration
• Game: examine the different skeletons

⇒ Workshop 2 – Spines, plates and skeletons

1. The arms race

Under the effect of natural selection, animals that were the prey of others developed defence systems such as spines and thick shells, while the predators developed arms such as pointed teeth and prehensile feet and hands. This arsenal was thus the result of a race between the hunters who had to catch their prey and the prey who had to escape from the hunters.

illustration
• drawings of carapaces, spines and claws

2. The first eyes

The first eyes appeared 542 million years ago, mainly among arthropods. These primitive eyes were simple cells which could tell the difference between light and darkness. Their gradual development improved the performance both of hunters and prey. This is another example of how the evolution of eyes, just like predation and biomineralisation, contributed to the intensification of interactions between species.

illustration
• interactive: comparison of different eyes
Workshop 3 – Ancestral models

1. Layout of the body

Despite the huge diversity of species, we can classify animals in 32 large groups, known as phyla, deepening on basic differences in their body layout: symmetry, sub-divisions, limbs, position of organs, etc. Almost all the modern phyla already existed during the Cambrian Period. At no time after that did the animal world experience such diversification of body layout.

Illustration
- PC: interactive game about body layouts

488 million years ago ➔ ➔ ➔ ➔ 416 million years ago

Forms of life diversify. The first fish appear

In the teeming waters of the Devonian Period

During the Devonian Period, a huge ocean covered most of the Earth. Close to the continental land masses, shallow, warm seas formed lagoons teeming with life.

Illustration
- Interactive video: continental drift

1. Abundant but vulnerable

The trilobites reach the peak of their success. From the tiniest to the largest, they had very different lifestyles. Some burrowed into the sedimental mud, others moved across the sea bed and others swam freely. They went into a rapid decline at the end of the Devonian Period and became extinct 225 million years ago.

2. Belgian lagoons

It is difficult to imagine our country as a coral reef bathed in a warm sea, and yet this is what it was during the Devonian Period. Huge reefs, hundreds of kilometres long, sheltered all sorts of life-forms. Trilobites, crustaceans, gastropods, jellyfish and fish all found shelter and food there.

3. The first jawbones appear

The armour-plated, jawless fish at the start of the Devonian Period gradually diversified. In some fish, the fine blades of bone which supported the gills turned into jawbones, some of which were armed with teeth. This change would profoundly affect food chains. It gradually took hold in all fish, and, by the end of the Devonian Period, fish without jaws were very rare.

FOCUS

Pteraspis/ Coccosteus

This Pteraspis did not have jaws. To feed, it sucked in tiny particles and small organisms from the sea. Coccosteus had moving jawbones which were able to be used to seize prey, despite having no teeth.
4. Filter to eat

Brachiopods were abundant in the seas. Although they are often confused with bivalve molluscs, their internal layout was different. They fed on particles in suspension in seawater, and most of them became extinct long ago. They played a key part in the Devonian Period marine community and were at the bottom end of food chains.

5. Living ballast

Goniatites first appeared at the end of the Cambrian Period and were quite similar to modern-day Nautiluses. Their rolled-up shells were divided into a series of ever-larger chambers, and the animal lived only in the largest chamber. The other chambers were filled with a gas, whose quantity could be changed by the creature by a chemical reaction, allowing it to rise and fall in a column of water.

6. The rise of fish

Many fish were protected with armour which protected the rear part of their bodies, which was very useful in protecting them from predators such as giant sea scorpions! But a new type of fish would develop which looked more like modern-day fish: the bony fish. Some had striped fins, others had fleshy fins and would develop into tetrapods.

**arcopertygian / Actinopterygian**

What is the difference between these two fish? Their fins. One has fins supported by a fan of thin bones linked by a membrane, the other has fins whose central parts are made of moving bones and muscles.

7. Green colonisation

From before the Devonian Period, land close to the coasts began to be invaded by lots of small plants. Their presence would have a profound effect on the soil. Later, the appearance of spores and then seeds would allow vegetation to invade the land. Leaves, needles and roots developed, as did wood, which allowed plants at the end of the Devonian Period to attain great heights.
1. Without jawbones or teeth

The first fish had simple forms, without fins other than their tails and without jawbones. Most of them lived on the sea floor, sucking up sediment to extract soft food from it. Others fed on the plankton suspended in the seawater by filtering seawater. Other types of fish had discs covered with sharp, grating spines which suggests they were parasites like modern-day lampreys: they were used to attach themselves to prey and then to eat the flesh of their prey.

Illustration
• 3 drawings: mouth of a lamprey, fish without jawbones and teeth.

2. The first jawbones

Jawbones evolved from the rigid cartilage arches which support the gills. The two components of the first arch evolved into the first upper and lower jawbones. Then the second arch moved towards the first to reinforce and support the jawbones.

Illustrations
• 3 casts: from gill arch to jawbone
• Interactive game: with or without jawbone

3. Advantageous innovation

Fish with jawbones had a competitive advantage: they could more easily extract oxygen from the water via their gills and they could eat new sorts of food. The opening and closing of their jaws pumped water into their mouths more quickly and thus better irrigated the gills, even when they were not moving. The jaws could also be used to hold prey before swallowing it. The fish with jaws therefore became active hunters.

Illustration
• Experiment: passage of water enriched with oxygen through the gills

4. A big mouth

Placoderms were the first large fish with jawbones. The rear part of their bodies were covered in thick, articulated, armoured plates. Their very powerful jaws allowed them to shred their prey. Although they lacked true teeth, the bones had cutting-blade-like protuberances. These large predators dominated the seas for a long time before becoming extinct at the end of the Devonian Period without leaving any descendants.

Illustration
• 6 drawings of different placoderms.
5. A variety of shapes and implantations

Fish had teeth on their jawbones, but some also had them on their soft palate, tongue and pharynx bones. Teeth in the mouth were mainly used for grabbing food. The teeth near the pharynx were used for chewing food or for dragging it towards the oesophagus. Teeth were adapted to the fish’s food: herbivorous fish had cutting teeth at the front of their mouths, whereas the fish who ate coral had large, fused teeth at the back of their mouths.

**Illustration**
- Video on fish teeth and jaws

⇒ **Workshop 2 – fins and feet**

1. Fins, another innovation

Fish with jaws had another innovation: front and back pairs of fins. They helped the fish manoeuvre more easily, to change their appearance and to stabilise their bodies. We imagine that the genes which had been responsible for the development of the head-to-tail axis began to function in a new way, which led to the appearance of pairs of fins and later of limbs.

**Illustrations**
- Interactive PC game: different fins
- 3 drawings of fins

2. Two types of fins

Fish with jaws evolved into two groups: cartilaginous fish and bony fish. Some bony fish developed into fish with fan-like fins which enjoyed a great evolutionary success in terms of diversity, while other developed into fish with fleshy fins like modern-day coelacanths. This group would also evolve into the first land-dwelling vertebrates.

**Illustration**
- Experiment: compare fins with two videos

3. The first feet

Feet evolved from fleshy fins, whose structure prefigured that of feet: they had a central axis made up of three bones, one at the base and two others next to each other, as in tetrapods’ feet. Many bony struts in a fan shape supported the end of the fleshy lobe containing these bones. A major step forward occurred when these fan-shaped struts were replaced by toes, which would enable the animals to walk on the dry land.

**Illustration**
- 2 casts of a fin and a foot
359 million years ago

Plants continue to colonise the continents

**CARBONIFEROUS Period**

Living in the Carboniferous Period forests

In the Carboniferous Period, the climate started off hot and humid and gradually became drier. The modern-day continents formed one super-continent, Pangaea, surrounded by a huge ocean.

**illustration**
- Interactive video game on continental drift

1. **The continental challenge**

The colonisation of the Earth was a progressive process. In the Carboniferous Period, plants grew in marshy forests with their roots underwater, and it was not difficult for them to leave the aquatic environment. They had to develop a resistance to drying out and had to find a way to seek water and nutrients from the soil and a way to grow upwards, despite their weight. Cuticles, stoma and woody tissue were developments that responded to these challenges.

No, this is not alligator skin! It is the trunk of a sort of tree-fern which could grow to 33 yard tall with a 3 feet-diameter trunk. The marks you can see are scars left by fallen leaves as it grew.

2. **Seeds, another tactic**

Until then, species had been dispersed by thousands of fragile spores which were only fertilised later if the climate conditions were right. By contrast, seeds were the result of fertilising ovules in the plant itself, they were bigger and contained reserves of food in a waterproof membrane which both protected the young shoot and provided food for it.

3. **Step by step**

Animals followed plants closely in their colonisation of the dry land. Some arthropods were among the first to leave the water: their carapaces protected them from drying out and their articulated feet made it easier for them to move around on the dry land. Very soon after, other animals, such as spiders and gastropods, followed them. The vertebrates and tetrapods were the last to move to dry land.

4. **The insect boom**

As plants diversified, insects transformed themselves. Some began to fly thanks to new organs called wings, which had evolved from tegumentary extensions to sections of the thorax in some and from appendices at the same level as the legs in others. Before they developed to permit flight, they were used for other functions such as signalling alarm, mating rituals, regulating body temperature and camouflage.

5. **Evolution continues**

We are sometimes so fascinated by the animals which left the seas that we forget that life in the seas continued to evolve.
Corals, brachiopods and crinoids populated the sea floor and continued to diversify. Fish continued to transform themselves: new types of shark appeared and bony fish became dominant among marine vertebrates.

→ **Workshop 1 – Lungs and throats**

1. **Exchanges of gases**

When they breathe, animals take in oxygen from the air or water and give out carbon dioxide. Oxygen is used to burn food and to extract energy from it. Carbon dioxide is a waste product. These gases are exchanged via passive diffusion, depending on their concentration, at the thin wet layer which covers the respiratory surfaces, which, depending on the animal, can be on the skin, the gills, in the throat or in the lungs.

**illustrations**
- Video & Audio: How to breathe in the air and underwater.
- 4 3D models of different lungs

2. **The first lungs**

Lungs allow animals to absorb oxygen from the air. The first lungs had no bronchia and appeared in fish before the colonisation of the dry land by tetrapods, as an adaptation to cope with life in poorly-oxygenated water. Some modern-day fish, the descendants of the first fish with lungs, still have both lungs and gills. These lungs function and can be used for a significant part of the animal’s breathing. These fish regularly go to the water’s surface.

**illustrations**
- Video: the first lungs
- Drawing: breathing process in a fish with lungs

3. **Route of oxygen**

The air breathed in is rich in oxygen and goes down to the lungs via the bronchia which sub-divide into finer and finer tubes until the air arrives at the pulmonary alveoli, small sacs covered in blood vessels. The membrane separating the alveoli from the capillaries is very thin, and allows the exchange of gases: oxygen from the air passes into the blood and waste carbon dioxide is eliminated to the outside air.

**illustration**
- 3D model: respiratory system, heart and lungs

4. **A question of efficiency**

Two changes improved the respiration of terrestrial tetrapods. The first was the development of open nostrils, allowing air to pass from the nasal cavity to the pharynx, thus giving the nose a role in respiration and allowing the animal to breathe while its mouth was closed. The second was the development of the muscles surrounding the thorax, which transformed the thorax into a sort of pump, which greatly improved the entry and exit of the air in the lungs.

5. **A network of throats**

Insects breathe through a series of long tubes which extend throughout their bodies. The air from the outside enters through openings then flows down a series of progressively narrower tubes until it comes into contact with cells, where the oxygen contained in the air passes into them. In flying insects and larger insects which need more oxygen, the contraction of the wing muscles, or structures which resemble bellows, create an influx of air and thus of oxygen.
Workshop 2 – Walking on dry land

1. A lot of recycling

Arthropods were the first animals to leave the seas en masse, thanks to several anatomical predispositions: a rigid carapace which acted as an external skeleton and supported their weight, and which also prevented their dehydration; the development of their limbs into legs, and the presence of joints between the different parts of their skeletons which allowed them to walk on all sorts of dry terrain.

2. Weight resistance

On dry land, the forces playing on the spinal column are directed downwards. To carry the weight of the body and to move it required some changes to avoid the back sagging, to hold the head erect and to hold the internal organs in place. The bones became thicker, the belts of muscle around the shoulders and hips grew larger and the limbs became stronger. New and more powerful muscles appeared. The joints changed to allow freer movement.

3. A rolling walk

All the evidence leads us to believe that the first terrestrial tetrapods had well-developed joints, hands and fingers, strong bones and powerful muscles, and that their limbs were inserted laterally into their torsos, with elbows and knees pointing outwards. Modern-day salamanders still look like this. By extension, we think that the first terrestrial vertebrates moved in a similar way, with the torso rolling from side to side with each step.

Workshop 3 – Eggs

1. Insect eggs

Insect eggs are protected by a very thin membrane and an external envelope which is hard and waterproof. It prevents the absorption or loss of water and allows the eggs to tolerate a variety of environmental conditions. Inside, the vitellus provides food to the embryo during its development. Laid singly or in groups, protected by secretions or inserted into crevasses, the types of egg-laying are as varied as the shape, size and colour of the eggs.
2. Amphibian eggs

As they have no shells, amphibian eggs are vulnerable to dehydration. They are thus laid in water or in wet places, protected by a gelatinous layer which holds them together. Each egg is delimited by two thin membranes that are stuck together, and contains very little food, just enough to allow tadpoles to develop: aquatic larvae that will undergo further changes. Each species has its own egg-laying strategy and the adults only rarely look after their eggs.

Illustration

- 3 photos of eggs

3. Amniotic egg

An amniotic egg can be laid on dry land and allows the embryo to develop in an aquatic micro-environment, protected by a porous shell. In the egg, the vitellus holds the food stock and the allantoid allows the embryo to breathe and stores its waste products. Originally, the shell was a fibrous membrane which lined the membranes of eggs as in the frogspawn of the Coqui frog. The allantoid and the calcification of the fibrous membrane appeared later.

Illustrations

- Enlarged 3D model of an amniotic egg, showing its components
- 2 photos of amniotic eggs

Suddenly, 225 million years ago, 95% of species became extinct

225 million years ago ➔ 199 million years ago
The survivors gave birth to new types of animals

In the Jurassic seas

During the Jurassic Period, the super-continent of Pangaea broke up and the Atlantic Ocean was created. All over the Earth, many shallow, warm seas were formed.

Illustration

- Interactive video: continental drift

1. Famous molluscs

Most cephalopods became extinct during the Permian-Triassic extinction. Only a few survived and gave birth to a great variety of ammonites, which were common in the Jurassic seas. From small to very large, they were distinguished by their ornamentation and by the wavy lines – called sutures – that appeared on the outside of the shells, created by the walls of the internal chambers.
**Belemnite**

Here is the skeleton of another cephalopod, a belemnite. Look at the crushed part, it is the same as the rolled-up structure of the ammonites. It was all covered with thick, muscular tissue, which made the animal look like a modern-day cuttlefish.

---

2. **A solid carapace**

Crustaceans lived in the seas of the Cambrian Period. Like the other groups of animals, they were almost wiped out in the Permian-Triassic extinction, but very soon afterwards they began to quickly diversify again. In response to the growing pressure of predation, new species, with thicker carapaces, appeared, forcing them to live on the sea bed rather than to swim around freely.

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3. **Alimentary relationships**

The alimentary relationships between species creates a complex web. The animals on display here paint a theoretical picture of this web.

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3. **Fossilised shellfish**

Although they were significantly affected by the Permian-Triassic extinction, bivalves managed to repopulate the seas quickly. The Jurassic seas were home to a wide variety of shellfish, many of which resembled modern-day shellfish. They had a variety of lifestyles: some lived inside cavities, others used a byssus to affix themselves to a hard substrate and others moved around on the sea floor.

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4. **Ecosystems**

Ecosystems are structured by the relationships between predators and their prey. Plants which synthesise organic matter from solar energy and mineral salts are at the bottom of the food chain, as they were eaten by animals which were then eaten by predators.

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4. **All sorts of fish**

With their circular mouths equipped with powerful muscles, robust scales and an asymmetric tail, the bony fish known as holostians remained dominant. Little by little, they would be challenged by another type of fish, the shark, which was faster and which had a perfected jawbone. Most of the sharks (cartilaginous fish) already had their modern-day shapes.

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5. **Technical improvements**

These modern-day fish, the teleostians, have an articulated jaw which points forwards and closes with a snap. They can therefore grate up coral or pick up food from the sea floor or inhale their prey. Their fine scales increase their swimming speed. Today, this group contains over 20,000 different species.

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6. **Sea teeth**

Cartilaginous fish, which include sharks and rays, are not very well known to palaeontologists. As they had neither an outer shell, nor an internal bony skeleton, they fossilised badly. Normally only their teeth and their scales became fossils. However, we know that sharks that looked like modern-day sharks were present in the Jurassic seas.
7. Sea-lilies

Crinoids have existed since the Cambrian Era. They were also badly affected by the Permian-Triassic extinction and experienced a revival in the Mesozoic Era, developing shapes with flexible arms. These strange creatures filtered the seawater which passed through their arms to feed on single-cell seaweeds, invertebrates’ larvae and small crustaceans. Most attached themselves to a substrate such as a floating tree-trunk or a coral reef.

8. Large predators

The reptiles rapidly took over the seas and became the top marine predators. Ichthyosaurs cruised around the open seas and mostly ate belemnites and small fish. Plesiosaurs, with their small, pointed teeth, hunted from hides and fed on fish and soft-shelled cephalopods.

9. Get into the water

Originally terrestrial, reptiles proliferated and diversified. Some acquired characteristics that suggest they lived in water, where they could feast on the plentiful sea creatures. Others adopted an amphibian lifestyle, such as crocodiles and turtles. Others, such as the plesiosaurs and the ichthyosaurs, ventured far from the seas.

10. Like a dolphin in the sea

A hydrodynamic body is the result of the shortening of the neck, a powerful tail which beats from left to right and four swimming fins: the ichthyosaur was adapted for marine life. Its method of reproduction also changed significantly: while most reptiles lay eggs on dry land, the ichthyosaur hatches its young at sea.

11. Eat or be eaten

The relationship between predators and their prey led to many changes, as much as in weapons for attack as in means of defence. While the reptiles at the top of the food chain appear the most frightening to us, they are also the most vulnerable because their survival was linked to the balance of the entire ecosystem.
Ammonites: hunt and ambush

On the right is a good swimmer. Its hydrodynamic shell and its ability to violently expel the water from its body allowed it to rapidly pounce on its prey. On the left is a huge, slower hunter who laid in wait for its prey on the sea beds.

12. The horns of Amon

Ammonites were very common in the Jurassic seas and derive their name from the shape of their shells: the Egyptian god Amon was depicted with ram’s horns. Hundreds of different species have been found. Their variety and their short lifespans and their wide geographical spread have delighted palaeontologists who use ammonites to date sediments of this Period.

Workshop 1 – Sea Reptiles

1. Adapted to life in the sea

Reptiles originally lived on dry land and could only live in the sea by evolving fairly major changes. While all remained air-breathers, others developed flippers in place of legs and reproduced in the water rather than on dry land. Their skin had both an advantage and a disadvantage: it was waterproof so prevented sea salts from entering the body, but it also prevented the elimination by sweating of excess salt ingested with its food: these were excreted via a gland which developed near their eyes.

Illustration

- 3D interactive model: how a fictional reptile adapted to marine life + video

2. From a leg to an oar

Some marine “reptiles” moved using swimming flippers, which had evolved from the limbs of their ancestors, the terrestrial tetrapods. To adapt to marine life, the limbs changed: the forearm and wrists became progressively shorter and rounded and their number increased considerably. The thumbs disappeared but additional fingers developed next to the remaining ones.

3. Underwater flight

The plesiosaurs were animals with huge, barrel-shaped bodies, with short, powerful tails which were used as rudders. Their four limbs were transformed into swimming flippers and they used them to “fly” underwater, like turtles, by flapping them constantly and slowly. Their movement downwards was achieved thanks to powerful muscles in the thorax, and their movement upwards was achieved by inertia.

Illustration

- Interactive: the plesiosaur’s underwater flight.

4. Adaptive convergence

The ichthyosaurs looked like modern-day dolphins with ribbed bodies, a stabilising dorsal fin and a tail adapted to caudal swimming. However, they also had four swimming flippers and moved forward by lateral movements of their tails and not by vertical movements. Their resemblance to modern-day dolphins, even though they are not in any way related, is due to their adaptation to similar living environments. This is known as adaptive convergence.
Workshop 2 – Eating and being eaten

1. Marine menu

Crinoids, sponges, gorgonia and shellfish were eaten by gastropods, starfish, ammonites, belemnites and crustaceans. In turn, these predators were devoured by fish, crocodiles and marine “reptiles”, which in turn were eaten by the largest marine “reptiles”. At the top of this food chain were the pliosaurs and the large ichthyosaurs, whose modern-day equivalents are killer whales and the larger sharks.

2. In reverse

Ammonites and belemnites swam backwards: the water was inhaled into a cavity of its mantle to oxygenate its gills, and then it was expelled by a contraction of the muscles of the mantle, which pushed them backwards. Expelled under pressure, the water exits via a siphon (a narrow tube that can be moved) which allow the creature to direct where it moved. Just like octopuses and squids, these animals could also shoot out a cloud of ink to hide their escape.

3. Like a goldfish

The success of the teleostian fish was due, in part, to their mobile jaws which allowed them to inhale prey and to grate coral. When the mouth opens, the jawbone moves forward. When the mouth closes, the jawbone moves back quickly, creating an inward current. These fish also had symmetrical tails and supple scales which made them quick and precise, and as good at escaping as at hunting.

Suddenly, 65 million years ago, there was another massive extinction and the dinosaurs disappeared.
The beginning of the Eocene Epoch was marked by very high average temperatures (50°F more than modern-day average temperatures). Then the temperatures gradually fell as the continents reached their current positions.

**FOCUS**

**Nipadites**
This fossilised fruit is that of a palm tree. It was not found anywhere exotic, but rather in the subsoil in Brussels! It is proof of the tropical climate experienced by our region at that time. The forests were filled with yew, fig and sequoia trees.

### 1. A tropical climate

Ten million years had passed since the Cretaceous-Tertiary extinction in which the dinosaurs, among others, had disappeared. The hot climate of the Late Cretaceous Period now became hotter, reaching its hottest point at the beginning of the Eocene Epoch, when average temperatures were 10°C higher than today. Tropical vegetation grew beyond 50° latitude in each hemisphere.

### 2. The rise of birds

The tropical climate encouraged the diversification of birds which had already begun before the Cretaceous-Tertiary extinction. Some birds developed into creatures which resembled modern-day birds, but others abandoned flight and became runners. Groups of giant running birds evolved to fill the void left by the disappearance of the large predators. The famous Dyatrima, by contrast, became an omnivore.

### 3. Success due to teeth

Mammals, which had first appeared 170 million years earlier, took advantage of the empty ecological niches and the warm climate to diversify and to spread over all the continents. One of the key reasons for their success were their specialised teeth: they had the large incisors of rodents, the flattened molars of ungulates and the canine teeth of carnivores, which allowed them to make the most of any available food resources.
Propalaeotherium
This small animal is the oldest ancestor of modern-day horses. It ate mostly leaves. It had not yet developed the large, relatively cubic teeth with a smooth surface for chewing that its descendants have.

Bat
The first bats appeared at the beginning of the Eocene Epoch and they looked quite like their modern-day descendants. Their origin remains a mystery, but their appearance coincided with the increased diversity of plants and insects, which made up most of their food.

4. New opportunities
The niches emptied by the massive Cretaceous-Tertiary extinction were gradually re-filled, sometimes by unexpected animals. For example, although the mammals had been terrestrial since their first appearance, some mammals now began to conquer the air, others colonised trees and others moved into the seas, which led to many key morphological changes.

Rhodocetus / Dorudon
The ancestors of whales were terrestrial. Look at Rhodocetus: although it was an aquatic creature, it still has four legs, while the hind legs of Dorudon which was more recent, have all but disappeared. Over time, the legs evolved into swimming flippers.

Plesiadapis
While not a primate, Plesiadapis lived in trees, as shown by the bones in its paws. Northarctus which was more recent, has the characteristics of a real tree-dwelling primate: eyes on the front of its head, opposable thumbs, finger-nails and toe-nails.
5. Survivors

The diversification of mammals and birds created a growing rivalry on the available dry land. The new arrivals became competitors of the species which had survived the great extinction. This was most obvious among the surviving “reptiles” who had to cope with the emergence of “modern reptiles” who were the ancestors of modern-day reptiles.

⇒ Workshop 1 – The Rise of Mammals

1. Climate change

At the beginning of the Eocene Epoch, a double rise in temperatures created a tropical climate. By the end of the Period, the climate became cooler and dryer. The Antarctic became covered in ice and the tropical forests were restricted to a narrow band and temperate forests and savannahs developed in the intermediate zones. Animal species changed from one generation to the next to adapt to these new living environments.

2. Migration of the mammals

55 million years ago, the climate quickly became hot and humid. The forests extended to even cover the polar regions and passages were created between Europe and North America. These bridges allowed mammals to migrate from one continent to the other. The most primitive mammals became extinct and were replaced by “modern” successors. These animals were small and weighed less than 10kg, which was probably linked to the very hot climate, as the larger an animal, the more it retains heat.

⇒ Workshop 2 – Teeth

1. The teeth of success

The success of the mammals was due to their teeth and how they grabbed and shredded food. Chewing requires molars, and all mammals developed primitive types of molars: the upper ones in most mammals had three principal cones. The evolution of a fourth cone was crucial for herbivorous mammals because it increased the chewing surface of the teeth and made them more efficient at shredding. Later, crests appeared between the cones and the range of teeth types increased.

• illustration
  • Video: Mammals and Climate

2. Harder enamel

When a mammal chews, the enamel of its teeth falls under the pressure exerted by one jawbone against the other. In the first mammals, this enamel was simple and made up of parallel fibres, set at an oblique angle to the tooth surface. Later, many groups of mammals, including the larger ones and the rodents, developed enamel made up of two intersecting layers of parallel fibres. This made a big difference: the enamel resisted the abrasion of food much better and was much less likely to chip or break while the animal was chewing.

• illustration
  • Video with audio: Enamel
3. Teeth put to the test

The teeth of the first rhinoceros tell us that it ate mostly leaves, which were very abundant at this time. The teeth of their descendants were adapted to grazing the savannahs, which were then expanding. Their ingestion of abrasive substances, such as sand, with their food, let to the evolution of thicker enamel, higher crowns and more cementum, and a change in the pre-molars from tearing teeth to chewing and crushing teeth.

→ Workshop 3 – New conquests

1. The conquest of the air

The first bats appeared more than 50 million years ago and were enabled to fly by changes to the bones in their front limbs: the radius became much longer and the cubitus shrank. The bones of the hands became longer and the fingers became hypertrophied, except for the thumb. The fingers were linked by a thin, elastic, supple membrane that was adapted for flight, and which extended from the front limbs to the hind limbs. Only the thumbs remained free of it, and were used to attach the animals to supports and to hang off them.

2. From the dry land to the sea

Whales are descended from hoofed mammals which moved to a marine environment. Their terrestrial ancestors became amphibious and then their rear legs shrank and disappeared. Their hips also atrophied and their front limbs became swimming flippers, even if the bones inside them remained the same as those of the fingers of a hand. In the head, the nostrils moved to the top of the skull, allowing them to breathe without having to lift much of their heads out of the water.

Illustration
- Interactive: the evolution of cetaceans

3. Climbing in the trees

The Plesiadapis group, which was close to the primates, had features adapted to life in trees: highly mobile arms, agile paws with fingers equipped with claws which could be used to climb trees. Their eyes were on the sides of their heads, whereas the primates, who appeared later, had both eyes on the front of their heads, prehensile hands and feet, one finger that could be opposed to the others and finger-nails and toe-nails which were better adapted to manipulating branches and twigs than claws.

Illustration
- Video: position of the paws for climbing trees.
34 million years ago ➔➔➔➔➔➔ the present day

From among the primates, one species emerges: human beings.

Evolution continues to the present day – Zone 1

Today, the average temperature on Earth is 15°C. Our planet has a wide variety of climates. The continents continue to move a few centimetres each year.

**Illustration**
- Interactive video: continental drift

**The brown bear**
Modern human beings first appeared around 200,000 years ago, but they are not the most recent species among mammals. For example, the brown bear first appeared a mere 70,000 years ago!

**The agile frog**
One-quarter of mammals, one-eighth of birds and one-third of amphibians are threatened with extinction. Among them is the agile frog, which is under serious threat of extinction due to the destruction of the forests where it lives and the water sources essential to its survival.

1. **The diversity of life**

   Today the Earth is home to almost 1.6 million different species of animals and plants. This huge number helps to stabilise ecosystems and helps them to survive. But for how much longer? Galloping urbanisation, climate change and the destruction of natural environments have overturned, if not destroyed, the planet’s original ecosystems and has placed many species under the threat of extinction.

2. **New species**

   New species are only rarely discovered, a phenomenon called speciation. They usually arise, for example, following the creation of a geographical obstacle (a chain of mountains, an arm of the sea, a desert) which prevents one or more species from covering their normal territory. The separated populations then evolve differently until they become two separate species, incapable of reproducing with each other.

3. **From one relative to another**

   In some cases, the population of one species spreads out around a mountain or along a valley. Over time, these separated groups become more and more different from each other.
Each group is able to reproduce with its neighbours but not with the more distant groups, which eventually become different species.

**Gulls**

Lesser Black-backed gulls and Herring gulls live together along our coastline but cannot interbreed. Are they two distinct species? There is no simple answer because there are chains of sub-groups of both types which can interbreed.

### 4. Humans are a factor in evolution

Human beings are not like other animals: their daily lives include actions which threaten the ability of many other animals to survive and reproduce. Human lifestyles lead to deforestation, pollution, climate change and urbanisation which cause far more problems than human predatory activities like hunting and fishing.

**Workshop 1 – New species**

#### 1. Living together

More than 300 species of cichlid fish live in Lake Tanganyika. They have developed from a few original species whose descendants have gradually evolved and diversified by taking advantage of different ecological niches which have slowly created more and more specialised populations. Small differences in size, shape, colour, decoration and food within these populations have accumulated until new species have been created, which remain sympatric, that is they live together in the same environment.

#### 2. Together but different

In the mating season, crickets attract a mate by a particular song, which differs from one species to another. Sexual selection created this specific barrier: the preference, developed over time, for one sort of song or rhythm or behaviour for one population has led to the creation of different species which live in sympathy, that is together and in the same environment.

**Illustration**
- Audio game: recognise insect songs

#### 3. Mosquitos in the Underground

The mosquitos which live in the London Underground are not the same as those which live in the open air! The underground species developed in a few decades from the open-air species. The two species live in different habitats and eat different food (mammals’ blood and birds’ blood) and have different lifecycles. They can still interbreed, but this produces a specific sub-group, the “Underground entrance” mosquitos.

**Illustration**
- Interactive game: variety of salamander species

#### 4. Ring of species

From its base in Oregon, the variable salamander spread South along the sides of the San Joaquin valley. On each side of the valley, the population divided into sub-populations which evolved over time. Still able to breed with close relatives, they formed a continuum along the valley. But when they met in Southern California, where the valley walls disappear, the two types of salamander could no longer interbreed: they had become two different species.

**Illustration**
- Interactive game: variety of salamander species
5. Fish in the desert

Around 10,000 years ago, Death Valley in the Western USA was covered in lakes and streams, which then dried up and the Cyprinodonts, a type of small fish that lived there, became trapped in the remaining small, isolated bodies of water, forming many sub-populations of the original population. These isolated sub-populations in their new environments slowly evolved into distinct species, adapted to life in each specific habitat.

Illustration
• Observation game: evolution of Cyprinodonts

Present Day - Zone 2

1. Artificial Selection

When humans keep livestock or cultivate crops, they select, change and deliberately encourage the characteristics they want in the plants or animals, and thus direct their evolution. This is therefore not natural selection but artificial selection because the animals and crops are chosen for economic or aesthetic reasons.

Pigs
The appearance of pigs has changed since they became domesticated. If you compare a wild boar to a pig raised for pork, you can see that the domesticated pig has a smaller head and larger hindquarters, which yield more meat.

2. Man the predator

By hunting and fishing, humans exercise selective pressure on certain animals. For example, statistics show that the average size of cod caught has gone down, because fishermen have reduced the size of the gaps in their nets so that only the smallest fish are not caught. As heredity influences adult size, smaller cod have become proportionally more and more common.

Workshop 2 – Manipulations

1. Ever more meat

The “Bleu-Blanc Belge” (“Belgian Blue-White”) breed of cow is the result of artificial selection, that is the choices made by breeders who were looking to create ever-more-muscular animals. Thus the breed, which was originally a dairy breed producing milk, gradually became a breed producing beef. It took several generations for these changes to appear, by breeders choosing the animals bearing the most meat and then breeding them with each other. Humans thus deliberately intervened in the evolution of this breed.

Illustration
• Drawings: evolution of the Belgian Blue-White

2. Victims of farmed versions

Following 25 years of artificial selection, the gene pool of Atlantic salmon has changed a lot and farmed salmon have become very different to wild salmon. Over the years, many farmed salmon have escaped from fish farms and have bred with wild salmon, producing hybrids, whose genes are spreading among the wild population so quickly that there is a risk that, in 25 years’ time, wild salmon will have disappeared.
Workshop 3 – Pressures

1. Not caught
The size of the gaps in fishing nets is a selection factor that has led, among other things, to populations of smaller cod, because the smaller cod stand more chance of not being caught in the nets, surviving and breeding. Their size is partially determined by their genes, which they transmit to the next generation, so over the generations the size of adult cod has gradually become smaller.

illustration
- Observation game: fishing for cod

2. Pressure of arms
Ivory hunters exert a selection pressure on elephants. As ivory is very valuable, the longer an elephant’s tusks, the more likely it is to be killed. Elephants with shorter tusks thus have more chances of surviving and reproducing, and the “shorter tusks” genes are more frequently transmitted to their descendants and thus become more common in future generations. Hunting thus contributes to the modification of the elephants’ gene pool.

illustration
- Video: hunting elephants

Workshop 4 – Rebounds

1. The antibiotics paradox
Antibiotics are widely used to kill bacteria. Although they are very efficient, there are nearly always some bacteria which carry a mutation allowing them to resist antibiotics. These few survivors reproduce and pass on this mutation and thus create drug-resistant populations. Which means that new types of antibiotics have to be used, which means that more mutations take place and so on and so forth…

illustration
- Audio-Video: resistance to antibiotics

2. Mutate and Resist
Humans have been able to kill fleas for more than 60 years with chemicals that attack their nervous systems. Little by little, fleas with a resistance to these chemicals have emerged. Genetic analysis of these fleas show that two significant mutations were responsible for their immunity. As the fleas that carried these mutations survived and reproduced, they transmitted the mutations to future generations of chemical-resistant offspring, who outnumbered those which were not resistant.

illustrations
- Photo of a flea (enlarged 100 times)
- Electron microscope photo of bacteria
34 million years ago ➔➔➔➔➔ the present day

From the present day to 50 million years from now.

This is fiction

THE FUTURE

A study of the movements of the continents in the past can help us predict their positions in the future. In 50 million years, Europe and Africa will have joined together, the Mediterranean Sea will have disappeared and Australia will have continued its slow rise towards Indonesia.

Animals of the future

1. Neopyghoscelis: Neozoic penguin
Length: up to 13 feet
Origin: Pygoscelis papua, the Gentoo penguin
Evolution: feet become swimming flippers, longer wings, (re-)appearance of pointed teeth

2. Rhombosepia: the rhomboid squid
Length: average 8 inches with some giant ones living in very deep oceans
Origin: Sepia officinalis, the common edible squid
Evolution: tentacles fused into two “jaws” that open to capture plankton; siphon (throat) shrunken and moved towards belly; hyper-development of mantle; displacement of water by traction.

3. Propellonectes: propeller petrel
Length: 3 feet
Origin: Macronectes halli, the Northern Giant Petrel
Evolution: new flightless form; atrophied wings; hyper-development of feet; hydrodynamic body shape.

4. Helicopodus: gliding centipede
Length: 10 inches
Origin: Scolopendra subspinipes, the Vietnamese centipede
Evolution: tail segment changes into “rudder”; fewer antennae; longer central motor cortex; larger eyes (to calculate distances); extremely longer back segments (that are able to move backwards and forwards along a longitudinal axis).

5. Trichopteryx: flying possum
Length: 5 feet including tail (tail is 2/3 of length)
Origin: Trichosurus vulpecula, the Common Brushtail Possum, a tree-dwelling marsupial
Evolution: prehensile tail becomes longer and more flexible; fingers and toes become much longer; fleshy folds between feet; ventral pouch opens towards tail (instead of towards head); hunts by stabbing prey.

6. Corticochaeris: grazing capybara
Length: up to 7 feet
Origin: Hydrochaeris hydrochaeris, the capybara, the largest rodent in the world
Evolution: shoulders and head massively enlarged; upper and lower incisor teeth much larger and protrude further.
Introduction: we are all related

1. The evolution of species is their modification over time. Through reproduction (young have to be produced) a unique genetic inheritance is transmitted to descendants, including mutations which appeared within this inheritance. If all offspring were identical to their parents, a species would reproduce but not evolve. It is this thanks to these changes, built up over millions of years, that such a wide variety of life forms have appeared.

2. All living creatures are descended from a single ancestor which appeared on Earth 4 billion years ago and which evolved into many different life forms. This evolution was the result of the simultaneous actions of two mechanisms. First the continuous, random production of new life forms. Second, natural selection which sorts these new forms of life and favours some while others become extinct. More than 90% of the life forms that have ever lived on Earth are now extinct.

Mechanisms of Evolution

1. From one species to two species
Sometimes, a group of individuals become separated from the others of the same species. As the two groups are no longer in contact, they evolve differently. Several generations later, the two groups will have accumulated different genes, behaviours and sometimes morphologies, so that they can no longer interbreed, even if they still look similar. The two groups have become two species: this phenomenon is called speciation.

2. Genetic drift
Even in the absence of the selection of advantageous features, not all the individuals in a species will have the same descendants. For example, some will have many offspring, some none. So in the following generation, the copies of genes belonging to the individuals who had the most offspring will be the most common. This changes the genetic diversity of the species and contributes to a change in its characteristics over time. Thus no species is fixed, all are continually evolving.

3. Inequality of chances
Among individuals that are born at the same time, some will succeed more than others in feeding themselves, escaping predators and finding a mate to reproduce. These individuals will have more descendants and will more efficiently transmit copies of their genes, which will include the genes which gave them these advantages. But an advantage in one environment may be a handicap when that environment changes.
4. Galloping evolution
Picture the first horses: small animals with feet with several toes which were adapted to life on the loose soil of forests. Following a change in the climate, the savannahs with their dry, compacted soil replaced the forests. In some animals, their central toe grew longer, ending in a primitive hoof, and the other toes became shorter, the legs became longer and the muscles grew larger. The animals found it easier to gallop and thus to survive in this new landscape.

Illustrations
• Audio-Video: horse’s hooves
• Casts: development of the horse’s hoof + specimen from fossil bed at Messel (Germany).

5. Milky drink, a genetic hotchpotch
Around 220 million years ago, a protein-rich liquid secreted by the cetaceous gland of a “reptile” underwent a remarkable transformation. Its antiseptic properties were used to protect eggs from infection. Following the unexpected duplication of some of its genes, the liquid acquired a nutritive value. From a complementary resource for eggs, the liquid evolved into milk, a food in its own right, and became the defining characteristic of mammals.

6. Similar but different
Not all the individuals in a species are identical. They look like each other because some of their characteristics are encoded in their DNA as copies similar to the same genes transmitted from generation to generation. But they have different heights, colours and aptitudes. Such variations reveal the differences they carry in their DNA. Whether or not they are visible, these variations are the result of the mix of the copies of the genes received from their parents, including any mutations.

Illustration
• Drawings: series of portraits

7. The architects of living creatures
Some genes programme the development of the embryo and the organisation of the body. Their action turns cells into muscles, bones, blood vessels, etc., and ensures that the body’s organs develop in the correct places. When mutations affect these “architectural genes”, the new individual sometimes develops an organ in the wrong place. If he or she survives, this change is passed on to his or her offspring. All animals have similar developmental genes because they all inherited them from a common ancestor.

Illustration:
• Multimedia: developmental genes

8. No exact copy
When a cell divides, it creates a copy of its DNA, which is not always an identical copy. Copying errors can appear spontaneously or when the DNA is damaged by external agents, such as chemicals or radiation. In most cases, the cell corrects the errors but sometimes a base is lost or replaced by another base. Every tiny difference between the original and the copy is a mutation.
9. Variation on the same theme
Each individual in a population is different. Many of these differences are passed on to its descendants because they are coded in its DNA, and this is how “favourable” characteristics can spread through a population, from one generation to another. This selection of a favourable characteristic is only possible because of the existence of variations between individuals.

10. The fruits of chance
When they reproduce, living creatures produce descendants to whom they transmit a copy of each of their genes. In animals which reproduce sexually, during fertilisation, copies of the genes of each parent combine in the new egg. But as each individual can carry slightly different versions of the same genes, each new creature inherits a unique combination. Thus the offspring are genetically different from their brothers, sisters and parents.

11. A single code for reading
In DNA, information is carried in genes, which are precise sequences of bases. The information is read and translated by molecular machines and leads to the production of proteins which create a specific morphological, physiological or biochemical characteristic. The code for reading and translating this information, which we call the genetic code, is universal, which is to be expected since it, like DNA, was inherited by all living creatures from their common ancestor.

12. The unity of life
Our cells contain Deoxyribonucleic acid (DNA), which has been passed down, from generation to generation from a single ancestor to most living creatures. DNA is the support for the information required for the development of all forms of life. It’s a sort of catalogue made up of a number of bases joined to each other whose sequence defines genetic information. These bases are adenine (A), thymine (T), cytosine (C) and guanine (G).

13. We are all descended from a single living organism

Illustration
- Interactive game: reproduction of a portion of DNA
- Variation in snail shells
- Interactive: formation of reproductive cells
- Interactive: a drop of DNA
- Interactive: zoom to the heart of cells
- Polygenetic mobile hanging from the ceiling
APPENDIX

Cambrian Period – The Burgess Shale

The Burgess Shale is around 505 million years old and was accidentally discovered by the American palaeontologist Charles Walcott (1850-1930). While walking along a path from Mount Wapta to Mount Field in British Columbia (Canada), he tripped over a piece of shale which contained a perfectly fossilised trilobite (arthropod). He returned to the site with his sons and several assistants, and the team uncovered a layer about a metre thick, from which the rock had come, and dug out the fossil-bearing rock. They took it back to their camp where they split it into sheets. Between 1910 and 1917, they unearthed almost 65,000 fossils. Their discoveries were featured in a series of articles published by Walcott between 1911 and 1913, which described around 150 species, belonging to 119 genera. The site was re-excavated in 1966 and 1967.

The Burgess Shale had been deposited at the foot of a huge underwater cliff. The very well-preserved fossils from the shale would provide priceless information on life during the Cambrian Period. The discoveries were all the more significant because they included so many fossilised soft-bodied creatures, which bore witness to marine life at the time. An analysis of the fossils revealed that some of the animals lived on the ocean floor, while others lived in the sediment or swam about freely. The dispersion of the fossils indicates that all these animals were buried under a mudslide which ended at the bottom of an ocean abyss. The absence of predators and oxygen there led to a magnificent fossilisation process. The huge pressure preserved the animals in the form of fine imprints. The high speed at which the animals were buried in the mud enabled their skeletons to be superbly preserved. The Burgess Shale fossils are a perfect illustration of the proliferation of complex life forms in the Cambrian Period, that has become known as the “Cambrian explosion”.

Figure 1: The Burgess Shale was deposited at the foot of an enormous underwater cliff. Animals living on or around the muddy ridges were swept away and then buried in the mud. Illustration © John Woodcock

This Cambrian reef was mainly inhabited by arthropods, but also by some other strange creatures, including Pikaia, a distant ancestor of the vertebrates. Pikaia could be described as a worm with a primitive spinal column and muscles laid out in a V-shape, like fish. Most of the arthropod fossils found were trilobites, but some other particularly well-preserved species were also unearthed, including Waptia (which resembled a shrimp) and Emeraldella (which looked like a trilobite with a long caudal spine). It is very difficult to classify many of these primitive arthropods.

Figure 2: Artist’s impression of the animals found in the Burgess Shale.

The classification of some other species is even more difficult. Aysheaia, an animal which resembled the onychophora, is perhaps the missing link between the arthropods and the annelids. Some of the Burgess Shale animals are so extraordinary that nobody had even imagined they had existed, but fossils are undeniable proof that they did.

Figure 3 Pikaia

Figure 4 Aysheaia
Although it does not appear obvious that there was a link between humans and fish in terms of the development of ears, it is far from impossible. We are not talking here about the visible external part of the human ear (the pinna) but the middle ear, between the eardrum and the inner ear (Fig. 1). A middle ear with three bones is one of the features of all mammals (along with body hair and the production of milk). Birds, reptiles and amphibians have only one bone in their middle ears (the stapes) while fish can hear without any bones.

The origin of the middle ear bones becomes clearer when the development of vertebrate embryos is observed. We have known for many years that vertebrates’ embryos strongly resemble each other at the beginning of their development (Fig. 2). Very early on, they develop four small ridges in the region that will become the throat. These will become the pharyngeal arches. The first two appear at about three weeks and the two others about a week later. Each ridge is separated from its neighbour by a small furrow. In fish, these furrows become deeper after a while and form the gill openings through which water flows, while the pharyngeal arches become the gills. In mammals, the pharyngeal openings usually remain closed.

The tissues of the first pharyngeal arch develop into the upper and lower jawbones and two of the middle ear bones (the malleus and the incus), together with their attached muscles, in mammals. The second pharyngeal arch develops into the third bone of the middle ear (the stapes), the hyoid bone (a small bone at the base of the tongue) and most of the muscles responsible for forming facial expressions. The third pharyngeal arch forms the bones, muscles and nerves located lower down the throat and used in swallowing (the cranial part of the pharynx). The fourth pharyngeal arch develops into the lowest parts of the throat, including parts of the larynx and its surrounding muscles.
Embryological arguments
In 1837, Karl Reicht was studying the embryos of reptiles and mammals when he discovered, to his great surprise, that the same pharyngeal arch – the first – went on to form part of the jawbone in reptiles while it formed two of the bones of the middle ear (the malleus and the incus) in mammals. In 1910, Ernest Gaupp reinterpreted the development of the pharyngeal arches from an evolutionist’s point of view. He suggested that the three bones of the middle ear clearly showed that there was a link between reptiles and mammals: the single middle-ear bone in reptiles was the same as the stapes in mammals. In both groups of animals, it had developed from the second pharyngeal arch, more precisely from the hyomandibular bone which links the upper jawbone to the skull in fish. The two other middle-ear bones in mammals develop from a bone which is located behind the lower jawbone in reptiles (Figure 3).

Fossil arguments
Fossil evidence was produced by W.K. Gregory in 1913. A continuum of fossils from reptiles to mammalian reptiles was undeniable proof that the bones to the rear of the reptilian jawbone, formed from the first pharyngeal arch, gradually became shorter and moved towards the middle ear where they became the malleus and the incus.

In this way, two different types of jawbones, one in fish and one in reptiles, gradually transformed themselves into new structures with a completely different function in mammals: the amplification of vibrations by the bones of the middle ear.

It must also be noted that the appearance of the middle ear shows a major transition in the history of life on Earth: the conquest of the dry land by the descendants of fish. Perceiving sounds underwater is not the same as perceiving them in the air. The first evolutionary change was the appearance of the stapes to amplify the perception of vibrations in the air. Then, when the mammals appeared, the bones from behind the jawbone in reptiles transformed themselves into the malleus and the incus. There are certainly less surprising things than the development of the ear as a link between fish and humans!

Source: “De Vis in ons” (The Fish in Us) by Neil Shubin, 2008, New Amsterdam, 255 pages.
Wings and flight first appeared in insects around 300 to 350 million years ago. They were the first and only invertebrates to acquire the ability to fly actively. This innovation explains without doubt their worldwide success. Flying allows insects to gain access to new spaces and new resources. If an environment became suddenly hostile, they could easily migrate to a new one. A flying insect can escape from predators more easily, and is also more likely to find a mate, even in a population spread over a wide area, which improves its panmixia and genetic variability. In a word, flight is a decisive discovery in the great competition that is evolution.

But how did insects learn how to fly? Unfortunately, we have not yet found any conclusive fossil evidence, and can thus only deduct and hypothesise.

First, close observation of the wings of insects – in particular their network of nerves – strongly suggests that all winged insects had a common ancestor: both the organs (wings) and the function (flying) only appeared once in the group’s history.

Wings

From what primitive anatomical structures could wings have developed? There are two opposing theories. The older theory suggests that wings developed from lateral extensions of the thoracic sclerite plates (part of the exoskeleton). These proto-wings are called “paranotas”. They were initially used by the insects to glide, and then the development of joints and hinges allowed them to flap the wings to create propelled flight. Some insect fossils from the Palaeozoic Period have paranotas, similar to structures on the bodies of modern-day silverfish. But there is no evidence of proto-articulation on these paranotas.

The second theory is more recent and is known as the “gills theory”. It is derived from observation of the larvae of mayflies which have dorso-lateral gills, shaped like foliules, which were articulated and had a blood supply, and which looked like tiny wings. These gills allow the mayflies to breathe underwater and are themselves the result of the specialization of a podite, the basal segment of a limb. This theory has been supported by observations by developmental geneticists, who have isolated similar genes in crustaceans (which still have primitive multi-gilled limbs) to those responsible for the development of wings in insects (in particular in fruit flies). In crustaceans, these genes lead to the creation of structures on the creatures’ backs, at the top of their legs.

Flight

Whichever of these theories is correct, we must also look at the advantage such “proto-wings” would have given the creatures, so that they were naturally selected.

The following scenario could well be true: at that time, insects lived in water. Once they had grown to adults, they climbed out of the water onto plants to mate, thus removing themselves from the threat of predators at a crucial time. To find a mate, they would move from plant to plant in short jumps, so any system which allowed them to slow down their fall or to glide even a little would be a selective advantage.

Another scenario has also been suggested based on the observation of the behaviour of modern-day stoneflies (Plecoptera). Some use their wings like the sails of a ship to skim across the surface of water, without really flying. Others use them like oars to row across the water in jumps. This suggests an possible evolutionary path for the gradual development of wings and the muscles necessary for “real” propelled flight.

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Jurassic – The amniotic egg

Introduction

Amphibians were the first vertebrates to move onto dry land, while remaining dependent on an aquatic environment, especially for reproduction. The development of amniotic eggs was a key development which allowed some vertebrates to move out of the aquatic environment entirely.

An amniotic egg has a semi-permeable shell and a group of extra-embryonic membranes which fulfil different functions. They are found among reptiles, birds and mammals (even if most mammals do not lay eggs). They are thus parts of the same group, called “amniotes”, all of which share a common ancestor.

Structure of an amniotic egg

![Diagram of an amniotic egg]

The shell (1) is impregnated with keratin, a fibrous, strong protein, or sometimes with calcium, as in birds. It protects the embryo (2) from shocks. It is waterproof and thus limits losses via evaporation, while allowing the oxygen required by the embryo to enter the egg.

There are four extra-embryonic membranes: the amnios (which gives its name to the amniotic egg), the vitellus sac, the allantoid and the chorion.

The amnios (3) surrounds the embryo and forms a cavity enclosing the amniotic fluid in which the embryo develops, and protects it from shocks and desiccation.

The vitellus sac (4) is a thin membrane with an abundant blood supply which extends all around the vitellus which, with the albumen (5) makes up the food store for the embryo. The blood vessels of the vitellus sac take nutrients from the vitellus to the embryo.

The allantoid (6) forms a sac in which the embryo’s waste products are stored. It is also used in the respiratory exchanges between the embryo and its environment.

The chorion (7) is the membrane which surrounds and protects the embryo, the vitellus sac and the allantoid. It is also used in respiratory exchanges.

Amniotic eggs are often large because they have large vitelluses, which enable the embryo to develop completely inside the egg, without having to pass through the larval stage, unlike fish and amphibians, whose eggs contain less vitellus, forcing the embryo to hatch prematurely as a larva, which can then feed itself. However, as amniotic eggs are larger, they demand more investment from the female that lays them and are produced in smaller numbers. In addition, whereas eggs laid in an aquatic environment can be easily fertilised by sperm that is simply released into the water, amniotic eggs require fertilisation to take place inside the female’s body before the shell is formed.

While amniotic eggs offer many advantages, there is the problem of how to manage the waste products produced by the embryo’s metabolism. In non-amniotic vertebrates (fish and amphibians), eggs are laid in water and the embryo expels its metabolic waste as ammonia, which is toxic but which is rapidly evacuated into the water through the egg’s membrane. But amniotic eggs are closed environments and the embryo cannot expel its waste products, so they are stored in the allantoid in the form of uric acid, so as not to pollute the environment inside the egg.

The appearance of the first amniotes:
The first amniotes appeared in the Carboniferous Period, around 350 million years ago. We do not know with certainty the process which led to the formation of the first amniotic egg, even though many hypotheses have been advanced. The lack of certainty is explained by the lack of fossil evidence, which is probably due to the fact that the first amniotic eggs contained very few minerals and thus had little chance of fossilising.

The evolution of amniotic eggs may have passed via an intermediary stage where amphibians began to lay large eggs in humid environments on dry land, rather like the modern day coqui frog (Eleutherodactylus coqui) which lays its eggs on dry land, and the embryo develops completely inside the egg, without passing through the larval stage when it can feed itself (tadpole). The eggs contain larger stock of nutrients, like those of amniotes, which meant that the frogs had to develop new structures within the embryo for the management of the vitellus and the metabolic waste, and the respiratory exchanges. These structures in E. coqui are similar to the chorion and the amnios in amniotes.

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1 The class of fish no longer exists in modern-day systems. We intend it to mean “myxinoids (hagfish), petromyzontides (lampreys), chondrichyens (sharks and rays) and the osteichyens (bony fish)”.

38  Evolution Gallery - Teacher’s Handbook
Genetic improvement

Since humans began growing crops, they have been seeking to expand and improve the range of plants that can be cultivated. For all plants contain a mixture of desirable and undesirable characteristics. Farmers and scientists seek to create new varieties which fulfil their needs and which possess one or more desirable characteristics. Thus they have selected plants with the highest yields, the best quality or the best resistance to diseases. This selection is a slow and laborious process. Desirable characteristics are introduced to a species by cross-breeding. The hybrids that result contain a combination of positive and negative characteristics. The best hybrids are then crossed with the original plant to produce the most commercial varieties. This process can be repeated from eight to ten times, until all the remaining plants share the selected desirable characteristic. The cross-breeding and selection process normally requires ten to fifteen years before a commercially-viable cultivar is produced.

From the end of the twentieth century onwards, genetic engineering began to appear in farming. Advances in biotechnology allowed scientists to directly introduce coding genes to produce a desirable characteristic in the host plant. This reduced the process of genetic improvement to its essence, it was faster than cross-breeding and made targeted selection possible. The basic difference from the traditional cross-breeding process is that genetic engineering enables the barriers between species to be crossed, so that host plants can be given genes coming from entirely different species, not just varieties of its own species.

Conventional genetic improvement

X characteristic of plant 1 that we wish to introduce into plant 2

Domestication

Humans don’t just select plants: they have also attempted to domesticate wild animals since they started to grow crops. They have used animals as a source of power, as companions or as a permanent source of food. Keeping livestock drastically reduced the importance of hunting. Domestication (from the Latin domus meaning ‘house’) occurs when wild animals become dependent on humans for food. Animals must possess certain biological characteristics that allow them to be domesticated: for example they must not be aggressive, they must accept the presence of humans and, to a certain extent, they must agree to obey humans. Animals that live in herds are generally easier to domesticate than solitary animals. Domesticated animals must also be able to stand the stress of captivity and be able to reproduce in captivity. To improve a breed of animal or to create a new one, humans must be able to decide which male will mate with which female.
The dog was one of the first animals to be domesticated. In the Goyet caves in the Condroz region, a dog’s skull around 31,700 years old was found, the oldest yet discovered in the world. Its teeth closely resemble those of a wolf: by contrast its muzzle was wider and shorter than those of fossilised or modern wolves. Prehistoric dogs no doubt looked like Siberian huskies but were the size of modern sheepdogs. They were used for hunting and transporting game. The manner of, and reason for, their domestication is still open to debate. One hypothesis states that domestication began when prehistoric hunters raised wolf-cubs that had been separated from their mother. It bases the history of canine domestication on human intervention to choose the wolf-cubs and to raise them. Another theory states that the wolf-cubs domesticated themselves, by seeking out human settlements where they could scavenge left-over food. In this case, selection was made on grounds of sociability, because aggressive wolves would have been chased away and would not have been able to benefit from the leftovers. After dogs, goats, pigs, sheep and cattle were domesticated around 8,000 BC in Western Asia. Domesticated horses first appeared around 4,000 BC in Ukraine.

Cloning

For centuries, plants were propagated by taking cuttings or grafting. This method, which produces several genetically-identical plants, is a type of cloning, although the term is more commonly used for mammals. Cloning also occurs naturally: twins with the same placenta are clones of each other. In common parlance, cloning refers to the deliberate separating of an embryo into several parts to create several new organisms. Recently, cloning by transplantation of nuclei has become possible. The genetic material from a cell of the mother is transplanted into an egg which is inserted into the surrogate mother. The offspring thus produced therefore does not carry any of the surrogate mother’s genetic material. In 1996, scientists used this technique to create Dolly, the first cloned sheep, who was followed by cloned rats, mice, goats, cows and pigs.

It should be noted, however, that all of these cloned animals had problems with their kidneys and brains and suffered from fertility and breathing problems, causing them to have unusually short lives. It appears that the adult genetic material introduced into the eggs had already “aged” and that its telomeres (the special DNA sequences that protect the ends of chromosomes) had already deteriorated. But all that is another story.
“The future according to Darwin”, article by Dieter De Cleene, published in the February 2009 issue of the journal EOS, based on an interview with Sébastien Steyer (the expert who designed the “Animals of the Future” part of the Evolution and Palaeontology Gallery of the Natural History Museum in Paris, and who works at the National Centre for Scientific Research.)

The future according to Darwin

In 50 million years, will the Earth be inhabited by giant rodents and penguins with teeth?

According to the French palaeontologist Sébastien Steyer, there is a strong possibility that the answer will be “yes”. Here he imagines how species might evolve in the future.

Charles Darwin came up with the idea that all living species were descended from a single common ancestor. Evolutionary mechanisms had led to the unbelievable diversity and richness of species that we know today: evolutionary biologists have developed increasingly precise pictures of how evolution moulded life on Earth for billions of years. But evolution continues today and will continue for thousands of years to come. Nobody knows exactly how life on Earth will evolve – “I’m not Nostradamus” says Sébastien Steyer – but by studying the past, scientists have been able to make more or less well-founded suppositions. Their research has revealed a sort of scientifically supported science fiction.

As a palaeontologist, Sébastien Steyer works at the National Centre for Scientific Research and is attached to the Natural Science Museum in Paris. He spends most of his time studying fossils, with the objective of learning more about the circumstances in which major evolutionary events took place. But that’s not all. Working with Marc Boulay and Sylvia Lorrain, both specialists in 3D computer modelling and organic sculpture, he has also attempted to glimpse the future. Yves Gaumetou then produced images as faithfully as possible of 6 animals of the future for the Evolution Gallery at the Natural Sciences Museum in Brussels.

You have projected some species 50 million years into the future. Why did you choose this precise number of years?

In the beginning, we tried to imagine what sort of animals would be living on Earth in 50 million years and in 200,000 million years. 50 million years seemed to be a good consensus figure because geologically it wasn’t that far away – geology is based on one-million-year periods – but it was sufficiently far into the future for clear changes to become evident. We called it the Dixonian Period after Dougal Dixon, who wrote the book “After humans, the animals of the future.”

Our vision of the future was based on current models of tectonic plate movements for the future. We also used climate models which gave us an idea of the climate in the future. We tried to sketch the physical conditions as best we could, and then we thought how life on Earth would adapt to them.

So you were able to imagine these animals of the future by studying the past?

Yes, by looking at evolution in the past, we were able to observe some recurrent models and concepts, for example evolutionary convergence: when two totally different species that live in a similar environment begin to look like each other. Dolphins, tuna and the extinct marine reptile the ichthyosaur are a good example of this phenomenon: these three animals belong to different classes – mammals, fish and reptiles – but live (or lived in the case of the ichthyosaur) in the water. They have adapted to this environment by developing hydrodynamically-shaped bodies, different types of sensors or sonar and a system of aquatic propulsion (either fins or swimming flippers, depending on the group). That is why they look so similar.

In your opinion, what will the world look like in 50 million years?

Our technical models indicate that the world will be completely different to the world we live in today. The Mediterranean Sea will disappear and Africa will come into contact with Europe, forming a new landmass which we have called Eurafrica.

The Mediterranean Sea will be replaced by a chain of mountains similar to the Alps, which will divide Eurafrica into two climatic zones. Indonesia and Australia will touch, which will stop the transoceanic currents between the Pacific Ocean and the Atlantic Ocean, which will have significant repercussions on the climate of the Southern hemisphere.

In 250 million years, all the continents will have come together again to form a supercontinent, which the modellers have called Neopangaea. Similar supercontinents existed 500 million years ago and 250 million years ago. We could almost consider this phenomenon to be cyclical.
Today, biodiversity is regressing. Some scientists even talk about a sixth mass extinction. How do you see the future developing?

Through the ages, there were several moments characterised by enormous biodiversity, followed by mass extinctions. Today, we are in a phase of elevated biodiversity which will be reduced rapidly in the future, mostly due to us. If we extrapolate the curve of the evolution of diversity during geological periods, it could be back at today's levels in 50 million years, following a huge crisis between now and then.

Penguins with teeth

What are the three ecosystems into which you classify the animals of the future?

We chose a marine ecosystem, a desert ecosystem and a forest ecosystem. For the marine ecosystem, we chose a zone in the South Atlantic, where the temperature is slightly higher than the current temperature of the polar seas, a consequence of the melting of polar ice. The second new ecosystem covers the desert separating the two parts of Eurafrica, south of the new mountains. The third habitat is a dense equatorial forest, where increased levels of carbon dioxide in the atmosphere could lead to trees growing to more than 100m tall, given that growing plants absorb carbon dioxide.

In each case, you have chosen almost all the present-day animals you use from among the vertebrates. Why?

We have observed that invertebrates haven't changed much, in terms of their morphology, during the history of life on Earth. For example, let's look at cockroaches, which have been living on Earth for 300 million years! We set out from the principle that they wouldn't change very much more in the future. Throughout our research, we bore in mind the fact that we had to understand the past if we wanted to understand the future.

How did you choose the existing animals?

On the one hand, we chose animals that had existed for a long time, because it is likely they will survive for a long time into the future. On the other hand, there were animals which we simply found amusing, such as penguins. And after all, this wasn't a 100% objective exercise, because education remains, after all, an unpredictable thing.

Next, we thought about what animals could look like in 50 million years. For example, snakes probably evolved from ancestors with limbs, which gradually disappeared over time. We imagined that the snakes of the future – Limaxopython – could become less mobile due to the enlargement of its thorax, but could catch its prey by hiding most of its body underground. The penguin is a bird which, today, seems well-adapted to its marine environment. We “turned the screw” to imagine it as an even more aquatic bird in the future. The result was Neopyghoscelis a formidable predator and a super-efficient diver.

One of the surprising characteristics of Neopyghoscelis is that it has teeth.

All birds are descended from dinosaurs, so the gene for the development of teeth has always been present in them. By using genetic modification, today it is possible, in the laboratory, to create chicks and hens with the beginnings of what could evolve into teeth. Of course, these chicks unfortunately don't live for long, but it is thus not entirely unthinkable that a similar gene would not manifest itself in the future.

Such mutations and such changes in embryonic development are really important to evolution, which we can define as a process in which external factors (such as climate, environment, etc.) limit genetic flexibility. Within a single generation, individuals who differ slightly from their peers can emerge. Individuals who have new characteristics can, of course, reproduce with their peers, which means that, at the same time, a new structure can emerge and be “tested”. If it produces an advantage in a particular environment, it can be selected.

The appearance of a new structure (or of a new organ) is often linked to the specialisation of a population to life in a particular environment. However, over-specialisation is risky, because if the environment changes, the over-specialised species will become extinct.

Another aquatic animal is the Propellonectes, another bird that has adapted to life in the water, descended from modern-day petrels. Which evolutionary processes could have led to the loss of its ability to fly?

This could have been caused by a reduction in numbers of flying prey, such as insects or other birds, or if flying predators became more powerful and dangerous. But the water could also become more attractive if aquatic prey, such as fish and octopuses, become significantly more plentiful.
The Trichopteryx, a “flying” marsupial which lives in trees, looks like a giant flying squirrel.

We thought about the changes which could be advantageous in the forest ecosystem. This is why we inverted the marsupial pouch, so that the young didn’t fall out when their mother was hanging upside down from a branch, and why we extended its fingers, to help it extract insects hiding in the tree-bark, and why we added folds of skin between its feet, so that it could swing from tree to tree. Some of these adaptations have already appeared in other species such as lemurs and flying squirrels.

Many animals become much larger, such as the Corticochaeris, a pretty large rodent. Why is this?

In most cases, species grow larger when they are in good condition. It is logical that Corticochaeris, which eats tree buds, roots and bark, would grow larger in our forest of the future. Look at humans. We have also become larger as we evolved, like other species which have enough food and do not suffer from too much competition.

The end of humanity

According to you, our end is fast approaching.

The oldest fossil of Homo sapiens dates back around 200,000 years. In geological and palaeontological terms, that’s like yesterday, and the figure becomes even more insignificant when you compare it to the age of our planet, which is about 4.5 billion years. We only need to think how quickly we can destroy our ecosystems and ourselves. Think about the demographic problems and the lack of raw materials which are already beginning to confront us. Evolution is a continuous process of the creation and extinction of species. Finally, each species, like each living creature, is born, lives and dies. I think that humans will quickly become extinct.

On the other hand, we are also extremely gifted at adapting to changing circumstances.

Yes, that’s true. There are also obvious positive factors, such as the advances in medicine which are ensuring we remain healthy for longer. But I think that our salvation will rather come from space travel, technology and the opportunity to travel to other planets. But what we really want to get across with this exercise is that evolution has not stopped with humans: it will continue forever, even if humans become extinct.
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