Nature's Techno Tricks

Biomimetics: science mimicking nature

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papawai

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Image opposite: Cranchiids are transparent, deep sea squids that maintain their position in the water column by means of a fluid-filled buoyancy device, and often have bioluminescent photophores (see pages 13 – 16 for more on bioluminescence and photophores).

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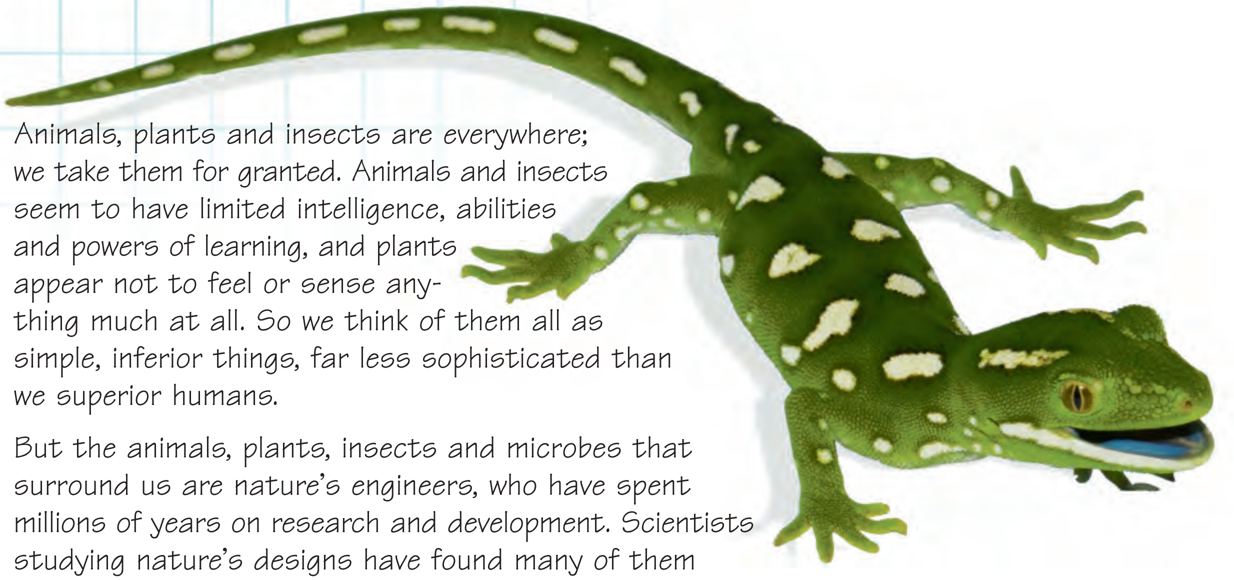
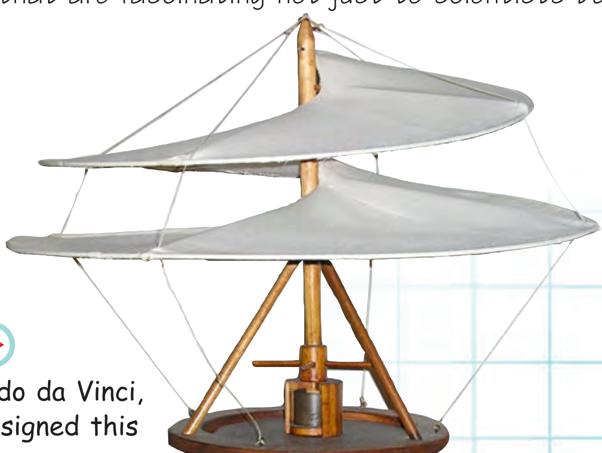
Nature's Techno Tricks



Animals, plants and insects are everywhere; we take them for granted. Animals and insects seem to have limited intelligence, abilities and powers of learning, and plants appear not to feel or sense anything much at all. So we think of them all as simple, inferior things, far less sophisticated than we superior humans.

But the animals, plants, insects and microbes that surround us are nature's engineers, who have spent millions of years on research and development. Scientists studying nature's designs have found many of them difficult to understand just because the designs are so very complex.

Using tiny cell factories and DNA blueprints, nature builds and rebuilds, designing organisms that are custom-made to survive in their special environment. Nature has been so busy perfecting the principles of chemistry, biology and physics that when you take a closer look you will discover many clever examples of nature's technologies; many clever technological tricks that are fascinating not just to scientists but to all of us.

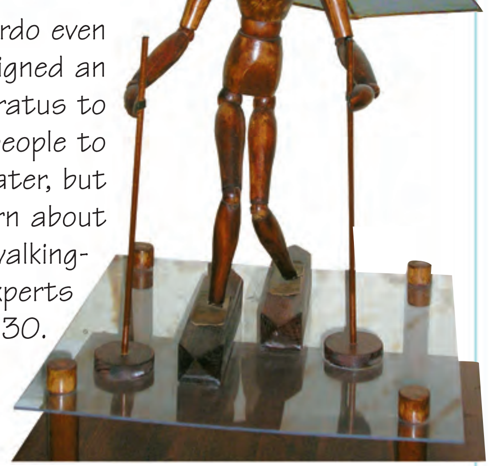


Leonardo da Vinci, who designed this aerial screw, was one of the first people to practice biomimetics.

Today, scientists all over the world are studying the designs and processes used by nature to discover how to manufacture new products or invent new technologies. This new science is called biomimetics, the science of "applying designs from nature to solve modern problems in engineering, materials, science, medicine and other fields" (Tom Muller, Biomimetics; Design by Nature, *National Geographic*, April 2008).

Leonardo da Vinci was a very famous painter and sculptor who lived nearly 600 years ago. To make sure his drawings and paintings were accurate, he examined everything in great detail and made many sketches. He studied hydraulics, mechanics, astronomy and engineering. Many ideas for inventions came to him when he was examining how nature designed the structures of birds, insects and animals. He recorded his thoughts and ideas in journals, and his curiosity and his observations led to his becoming a scientist and a great inventor as well as an artist.

Long before technological advances allowed people to build helicopters, aeroplanes, diving suits, tanks, automatic guns, submarines, water clocks or bicycles, Leonardo was envisioning machines of the future. He designed instruments for measuring wind velocity and machines for cutting the threads on screws, for making springs, cogwheels and pulleys.



Leonardo even designed an apparatus to allow people to walk on water, but to learn about nature's walking-on-water experts go to page 30.

Many people believe our future lies in computers and space-travel, but it is more likely that the ingenuity and inventions of nature's tiny organisms will hold the keys to unlocking future problems. Furthermore, nature's technology doesn't create pollution and its manufacturing processes are sustainable. The products are biodegradable, durable and practical in our world's ever-changing environment, and the designs allow creatures to perform multifunctional tasks.

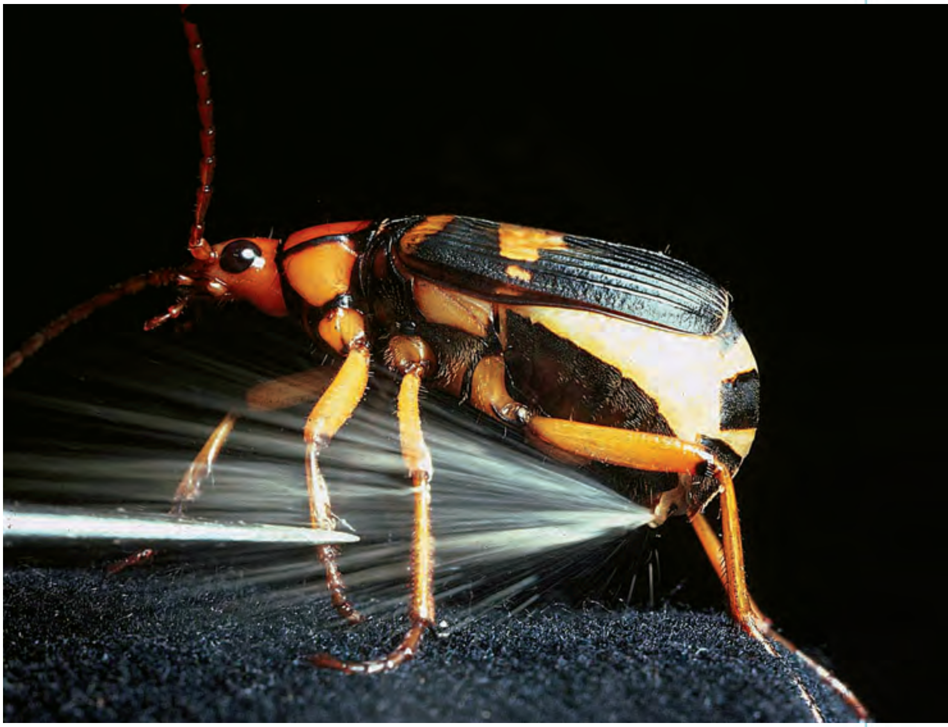
So what are these amazing techno tricks that scientists are investigating and trying to copy?

Chemical Defence Weapons

Beetles That Use Pure Rocket Science

Imagine a bomb-making beetle with a machine gun in its abdomen! When under attack the Bombardier Beetle uses just such a machine gun with its rapid-fire revolving gun turret to spray its very own chemical bomb over attacking insects.

In the 1950s German scientist, Dr Hermann Schildknecht, an expert on delicate chemical ana-lysis at the Erlanger University's Institute for Organic Science, discovered how the bombardier beetle uses rocket science to defend itself. He found that there was a bomb-making factory in the beetle's abdomen, with cells that make two very dangerous chemicals – hydroquinone and hydrogen peroxide – which are stored in special balloon-like sacs.



When under attack, simulated in this photo by the tweezers gripping the beetle's front leg, the beetle squirts the chemicals towards his attacker!

When in danger of attack by other creatures, such as ants, the beetle's muscles contract, squirting the stored chemicals out through valves into thick-walled, heart-shaped blast chambers, where glands release peroxidase.

Peroxidase acts like a detonator, triggering an explosion, and the resulting pressure blasts the corrosive chemical mix out through twin nozzles in the tip of the abdomen.

Light and the Magic of Iridescence

Properties of Light and New Technologies

Sir Isaac Newton (1642-1727) first discovered that white sunlight is composed of a mixture of colours when he passed a narrow beam of sunlight through a glass prism. The colours he saw were those you see in a rainbow – red, orange, yellow, green, blue, indigo and violet.

Light comes in a variety of wavelengths, which travel very fast. These wavelengths are made of tiny particles called photons and they have both electrical and magnetic fields.

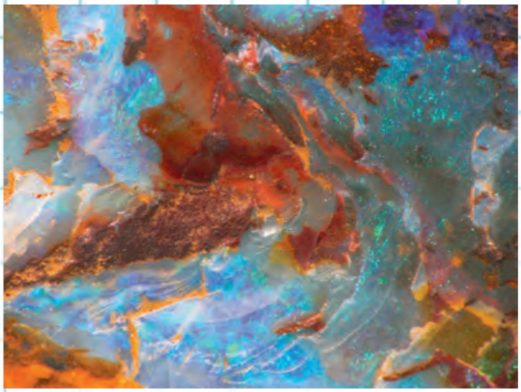
The movement of light waves can be controlled using diffraction gratings, a set of narrow reflective parallel slits that redirect light waves. The colours of the light spectrum that are reflected depend on the spacing of the veins and slits within the grating. An example of this technology that you see every day is the iridescent hologram on a credit card or a compact disc.

When the movement of light waves is controlled using diffraction gratings, optical discs like CDs and DVDs can use lasers to read information. This new science of diffractive optics – using lenses that scatter light waves instead of focusing or reflecting them – is providing scientists with ideas for new technology.

Optics, the science of light, is leading to many new discoveries. Both diffraction gratings and another light reflecting medium, the photonic crystal, are changing the way scientists think about optical lenses and offering exciting new opportunities in electronics and for designing solar cells, lighting, lasers and optical switches.

Light is increasingly being used to transmit and store information. Optical fibres continue to replace electrical cables for transmitting very fast signals over long distances.

A Bit About Photonic Crystals



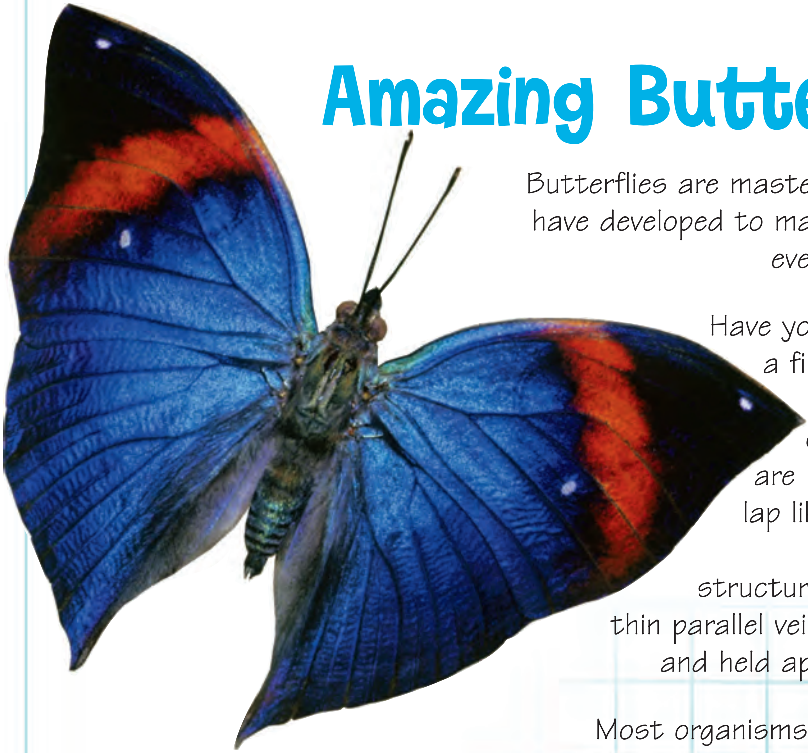
This opal contains a natural periodic microstructure responsible for its iridescent color. It is essentially a natural photonic crystal.

The science of photonics is similar to electronics except that in photonics, photons are used to carry information instead of the electrons.

Atoms in photonic crystals are spaced so precisely that they can capture light waves while controlling the direction of reflection. Photonic crystals act like mirrors reflecting the light at different angles, thus creating iridescence.

Because photonic crystals must be made on the same scale as the wavelength of light, they are very difficult to engineer without using the new science of nanotechnology. Nevertheless, scientists are excited by the challenge of creating photonic crystals that are so precise that only certain chosen wavelengths can pass through.

Amazing Butterflies

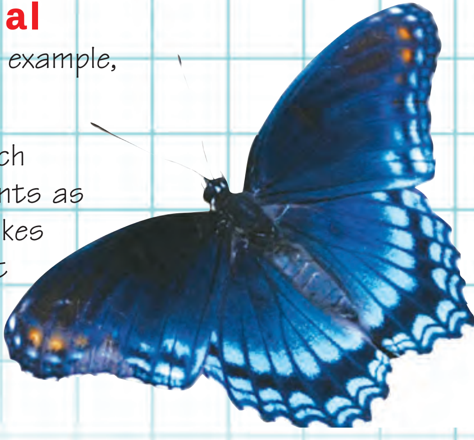


A Blue Morpho butterfly

Butterflies are masters of optics; the clever tricks they have developed to manipulate light with their wings rival even our advanced optical technology.

Have you ever handled a butterfly and felt a fine dust or powder on your fingers? The dust on your fingers is made of butterfly scales. Butterfly wings are made entirely of scales which overlap like the tiles on the roof of a house. And each scale is a complicated structure covered with diffraction gratings, thin parallel veins separated by hollow air pockets and held apart by vertical rods (see page 10).

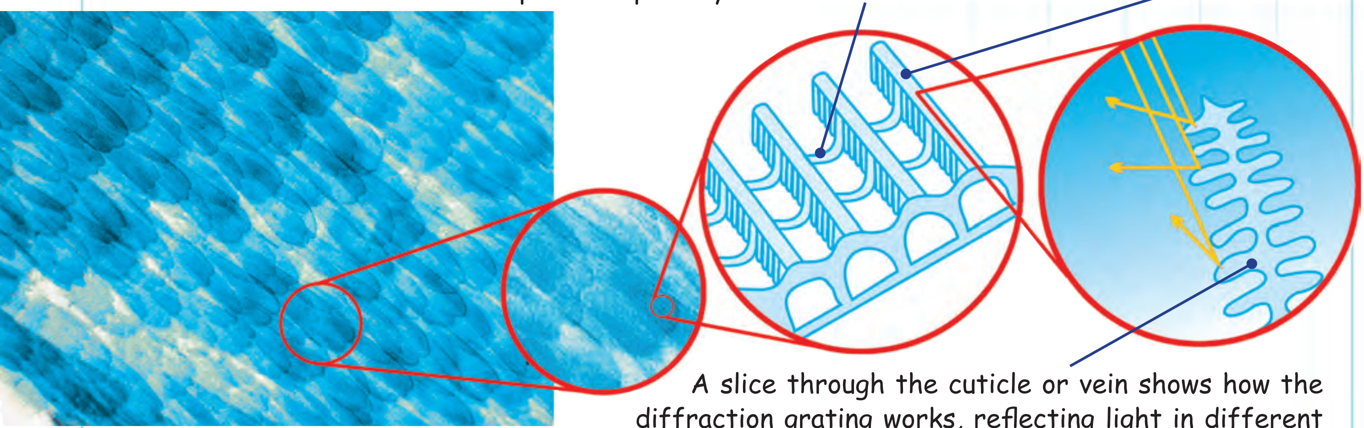
Most organisms contain biological chemicals called pigments which give them their colour. Pigments work by absorbing some colours and reflecting others. When light strikes an organism, some of the wavelengths are absorbed and others reflected, giving an appearance of one colour or another. In green leaves, for example, green is reflected and all other colours are absorbed.



Scientists have discovered that the iridescent colour of each scale in a butterfly's wing is created not so much by pigments as by the structure of the individual scales. When sunlight strikes the edges of the diffraction gratings in the scales, the light is split apart, wave by wave, and dispersed in many directions. When these light waves interfere with each other they produce the shimmering iridescent blues and greens, purples and yellows without the need for pigments.

Butterfly scales viewed under a microscope.

Detail of the scale showing the thin parallel veins held apart by vertical rods.



A slice through the cuticle or vein shows how the diffraction grating works, reflecting light in different directions.

The microscopic scales on the butterfly's wings also contain photonic crystals, which act like mirrors, reflecting the light at different angles, and creating even greater iridescence. Butterflies use iridescence to attract mates and deter predators.

In addition to diffraction gratings and photonic crystals, butterfly wings have a third light trick, a biological structure similar to the high-efficiency human technology called LEDs, or light-emitting diodes. LEDs are like tiny pieces of rock made up of various minerals, such as silica and gallium, the type and arrangement determining what colour is produced. Diodes in LEDs are illuminated by the movement of electrons in a semi-conductor material, and the technology is found in computer and television screens, digital displays and other objects, which light up without using light bulbs.

Portable Light Technology: weaving with light

The Huichol people of the Sierra Madre mountains in Mexico travel long distances and have no source of light at night. Researchers discovered a way to weave LEDs into the textiles woven by the Huichol people. They developed flat flexible solar panels that could be stitched onto the woven bags the Huichol carry, and then connected these to tiny batteries which were in turn connected to the LEDs. The solar panels collect the sun's energy during the day, and the bags become torches providing the people with bright white lights at night.

Bioluminescence or Living Light

Many fish live in total darkness, in the sunless depths of the ocean called the 'Midnight Zone', so they need to make their own living light called bioluminescence. Their bioluminescence either comes from symbiotic luminescent bacteria, or is made from a light-producing organ embedded in the fish's skin, called a photophore. The photophore can be quite simple, or it can be as complex as the human eye, equipped with lenses, shutters, colour filters and reflectors.

Ninety percent of the ocean is classified as the midnight zone, one of three zones based on the amount of sunlight they receive. The midnight zone is a region of total darkness extending from 1000 metres below sea level down to the ocean floor. Fish living in this zone use the food they eat to make the chemical luciferin and the enzyme luciferase. The luciferin reacts with oxygen in the presence of the enzyme luciferase, converting the chemical energy into light energy to produce a cold blue-green light. Blue wavelengths of sunlight travel farthest in seawater and the eyes of fish have adapted to see this colour. Bioluminescence is a very clever techno trick. Fish use their light to communicate with other fish, catch little fish to eat, find their way, lure prey and scare predators, and also to attract a mate.

While bioluminescence is primarily a marine phenomenon, it does occur in land-based organisms such as fireflies and glow-worms. In glowworms the light is used to attract insects which the glowworm catches and eats. If a glowworm is hungry its light will shine a little brighter and is even more effective. The female glowworm also uses the light to attract a mate.

Flashlight Fish

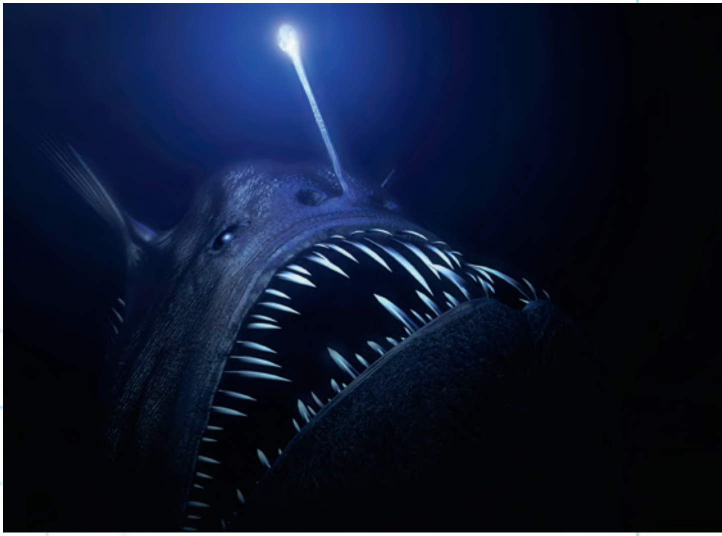
Flashlight fish borrow their light from light-producing bacteria living within their bodies. These bioluminescent bacteria live and grow in nutrient-rich blood vessels in special little pockets beneath the eyes of the flashlight fish. These pockets have a flap of skin, which can be raised and lowered to protect and hide the glowing bacteria.

Just like fish, these bacteria make light by using oxygen to produce a chemical reaction between the protein luciferin and the enzyme luciferase. When a school of flashlight fish is chased by predators, they zigzag, flashing their lights on and off by opening and closing their little eye pockets. This method of flashing and swimming allows them to escape their enemies.

So next time you are looking for batteries for your torch, think how useful some light-making bacteria would be.

The Angler Fish

Camouflaged to look like a stone on the seabed, the angler fish uses bioluminescence to catch dinner. Pointing forward and dangling in front of the angler fish's mouth, one of its dorsal fins wriggles in the water just like bait on a fishing rod. Light-producing bacteria live on this dangling lure. When small fish try to catch this glowing food, the angler fish opens its huge mouth and sucks them in.



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Water Wings: A Fog-Drinking Beetle

Imagine dying of thirst in one of the hottest environments in the world, the Namib Desert in Africa. Here endless orange dunes are blown into razor-sharp ridges stretching all the way to the Skeleton Coast. In the early morning when these dunes are blanketed by dense fog blowing in from the Atlantic Ocean, a shiny little black head-standing beetle is using a special techno trick to drink fog.

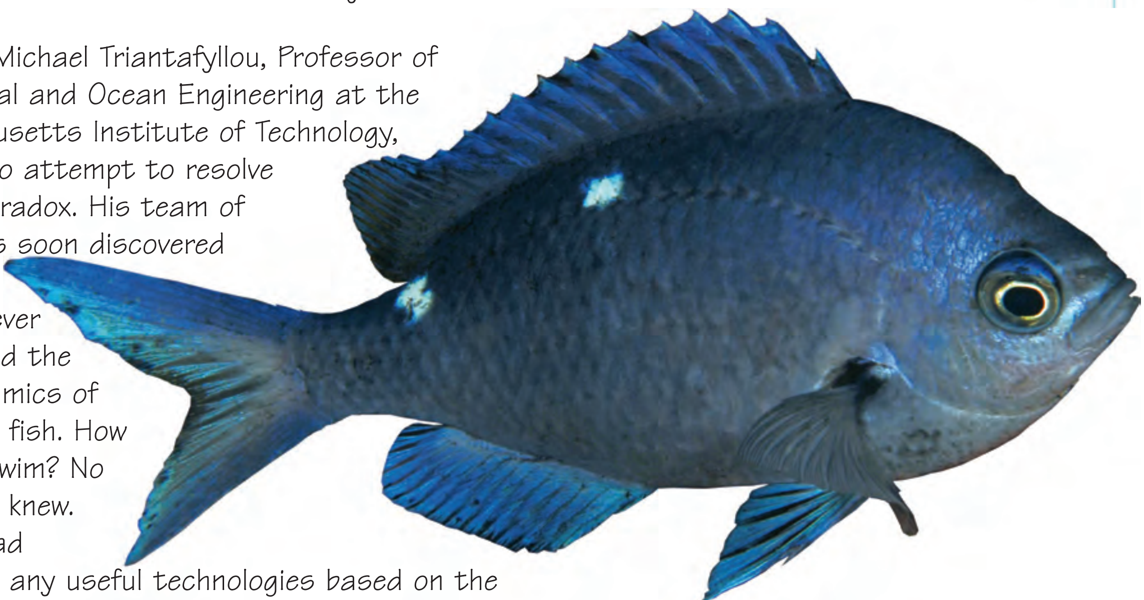
Wind blown fog travels so fast it will not condense on most surfaces. But this beetle with a bumpy back can capture a drink from microscopic droplets of water vapour. The trick to drinking fog is getting the droplets to collect and cluster together so the wind cannot blow them away. The tenebrionid beetle (*Stenocara* sp.) with its bumpy back, faces seaward into the wind, stretches its long back legs, tilts its body forward at roughly 45° and stands on its head!

Its shiny armour-like wing cases are fused together and covered with tiny bumps. A fog droplet collects on each little bump. More droplets begin to cluster together until they become heavy enough to roll down between the bumps and collect on the beetle's mouthparts. By the time the fog-drinking beetle has captured an early morning drink, it must find somewhere to hide from the baking sun.

Scientists studying this beetle have discovered that drinking fog is a neat trick made possible by the unusual bumpy surface on the fused wing cases (elytra). The smooth peaks are hydrophilic, or water attracting, while the troughs, with their wax

Swimming With Vortices

How fast can you swim in the ocean? That depends on how well you can overcome the mechanical forces, called drag, that oppose your movement through the water. Have you ever wondered how fish really swim? Well, in 1936, this very question also puzzled James Gray, a British zoologist. He studied the body shape of fish and calculated that fish are far more efficient swimmers than their body shape should allow. How did fish move so effortlessly? This question became known as Gray's Paradox.



In 1993, Michael Triantafyllou, Professor of Mechanical and Ocean Engineering at the Massachusetts Institute of Technology, decided to attempt to resolve Gray's Paradox. His team of scientists soon discovered that no one had ever researched the fluid dynamics of swimming fish. How did fish swim? No one really knew. No one had developed any useful technologies based on the way fish swim. To solve Gray's Paradox the scientists began work on the development of a biological robot they called 'Robo Tuna'.

In the 15th century, Leonardo da Vinci had tried to understand phenomena in nature by describing and drawing everything he saw in the utmost detail. His study of the human body and its anatomy led to 'Leonardo's Robot' the first robot ever recorded, which he designed around 1495.

Modern scientists also study the anatomy, physiology and behaviour of living animals to develop robots that closely resemble natural systems designed by nature – a technique called reverse-engineering. By studying the fluid dynamics of the Atlantic blue-fin tuna, scientists discovered that the body of a fish undulates as it moves through the water, creating differences in water pressure and causing a series of vortices which help to push the fish forward.

Fish increase their swimming efficiency by using these swirling patterns of water. When a fish swishes its tail, a jet of water is pushed backwards and the vortices, or swirls, in this jet of water generate thrust. Their swimming style is like the motion of a flag slowly flapping in the breeze.

Depending on the way fish wiggle, some vortices rotate clockwise and some anticlockwise as they roll along the body of the fish and into the path of its tail. Just by flicking their tails, fish are able to capture the energy contained in these vortices. Fish let the spinning water push them forward. Nature's clever trick solved the problem of drag for swimming fish.

Scientists hope the development of the well-known biological robot, Robo Tuna, which has the same fluid dynamics as the Atlantic blue-fin tuna, will show engineers how to build submarines and surface vessels that can use nature's principles of vorticity control.

A Bit About Vortices and Related Scientific Terms

A vortex (plural: vortices) is any spinning turbulent flow or spiral whirling motion. Easily seen examples include whirlwinds, waterspouts, and tornados. The whirling mass of water that sucks everything into the centre creates a vortex, for example, when water drains down the sink or bathtub.

A waterspout is a tornado over water rather than land.

When water passes a swimming fish, it becomes turbulent and flows into the void behind the moving fish creating a swirl of water on each edge of the fish. This swirl creates vortices, which reverse the flow of water behind the fish.

Vorticity Control

Turbulence is present everywhere in moving air, as well as in water. The propulsion system used by fish when they manipulate eddies that they encounter in water, and those they make for themselves by swishing their tails, is called vorticity control.

Drag

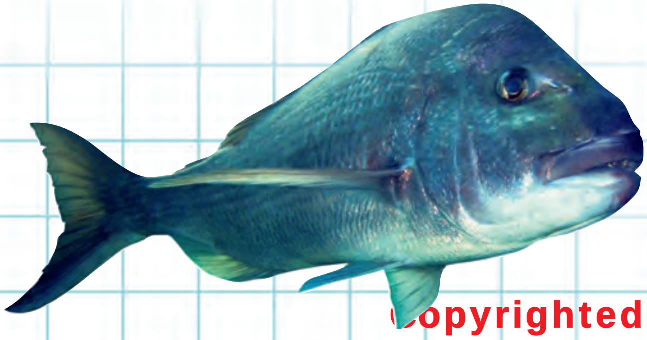
Drag is the name given to the force that opposes the motion of any object as it moves through water or air. In the case of fish, it is caused by friction between the molecules of water and the solid surface of the fish.

Reverse-Engineering

This is the process of re-creating something that already exists in nature. Using this process of observation and examination, scientists were able to discover how the Atlantic blue-fin tuna swims. With their new understanding of vorticity control, they were able to make their new robot based on nature's original design.

Fluid Dynamics

This is the science of fluids in motion and includes the various properties of fluids – velocity, pressure, density and temperature. For example, this science is used to calculate how the forces of turbulence, fluid friction and pressure variations affect the swimming ability of the blue-fin tuna.

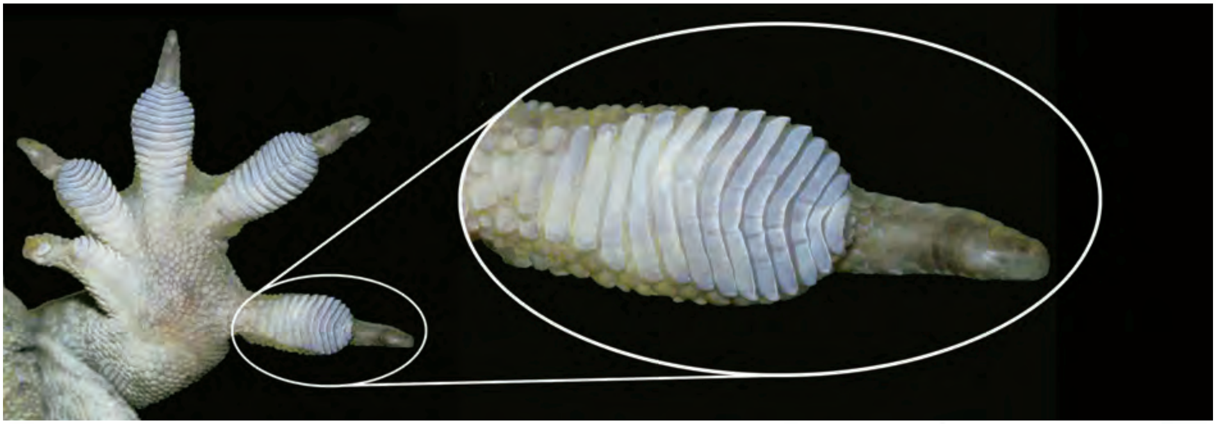


Eddy

An eddy is a current of water, or air, moving in a circular motion in the opposite direction to the main current. You can see eddies created by a large rock in a river when the water flows around it.

Each of the gecko's five-toed feet has a flat pad that is densely packed with ultra fine microscopic hairs called setae. Each hair is split into hundreds of flexible tips called spatulae. Spatulae are made of keratin, the same protein that is found in human hair. When geckos climb, the spatulae temporarily rearrange electrons on the climbing surface creating adhesive van der Waals forces. Geckos defy gravity by using very fine hairs!

Geckos use this amazing trick to stick and unstick their feet just like a Post-It-Note.



Scientists are developing an experimental "gecko tape". They hope this new material covered with nanoscopic hairs that mimic gecko spatulae will be used to make bandages that cling to the skin but peel off without hurting. Perhaps they will attach the tape to robots, enabling them to scale walls or crawl on ceilings just as the geckos do.

Did You Know...

Instead of an anus and a urethra, all birds, reptiles and amphibians have a posterior opening called a cloaca, from which they excrete both urine and faeces.

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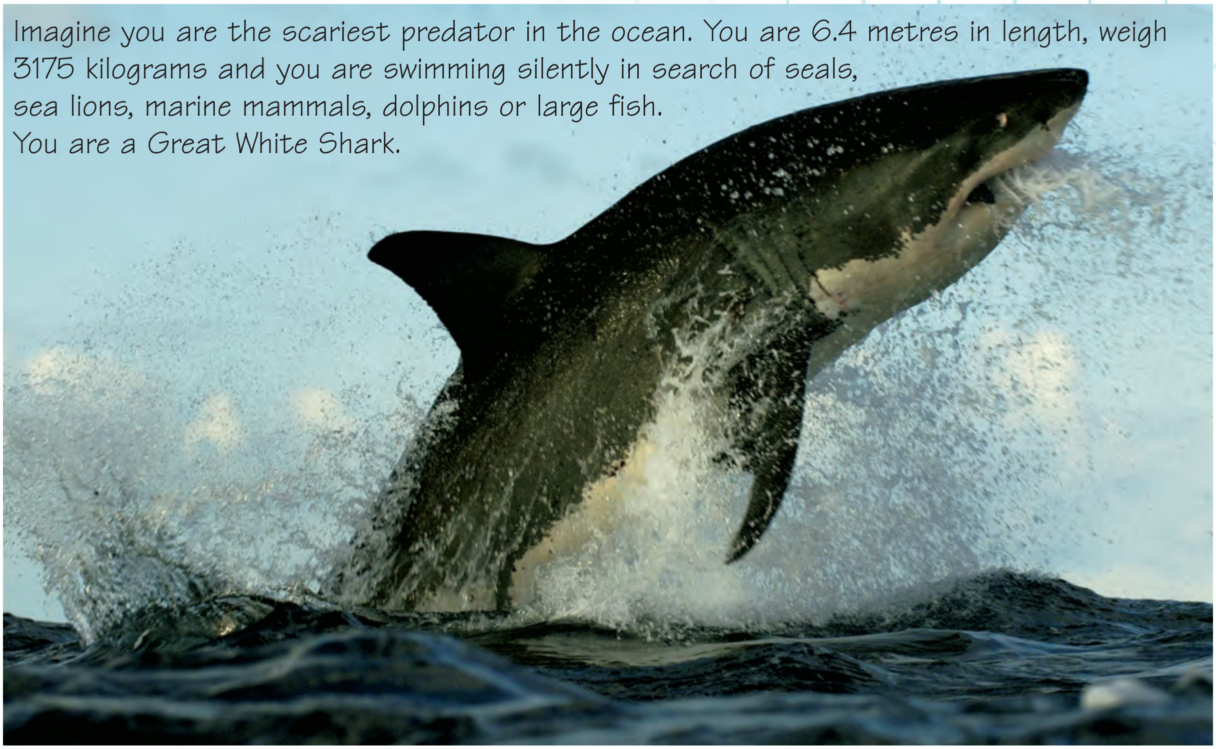
Electro-Reception: The Great White Shark

Imagine you are the scariest predator in the ocean. You are 6.4 metres in length, weigh 3175 kilograms and you are swimming silently in search of seals, sea lions, marine mammals, dolphins or large fish.
You are a Great White Shark.



Sharks rely on stealth, electro-reception and also on their super-senses to capture their prey as they navigate in a super-conductive, watery world. Their sight, hearing and sense of smell are all extremely sharp.

Light does not travel far in the ocean so shark eyes have developed special low-light receptors making them especially sensitive to the silvery flash of fish scales.

Oxygen is supplied through their gills, but chemical smells and odours carried on a steady flow of water are detected by a specially designed nose with sensitive nostrils.

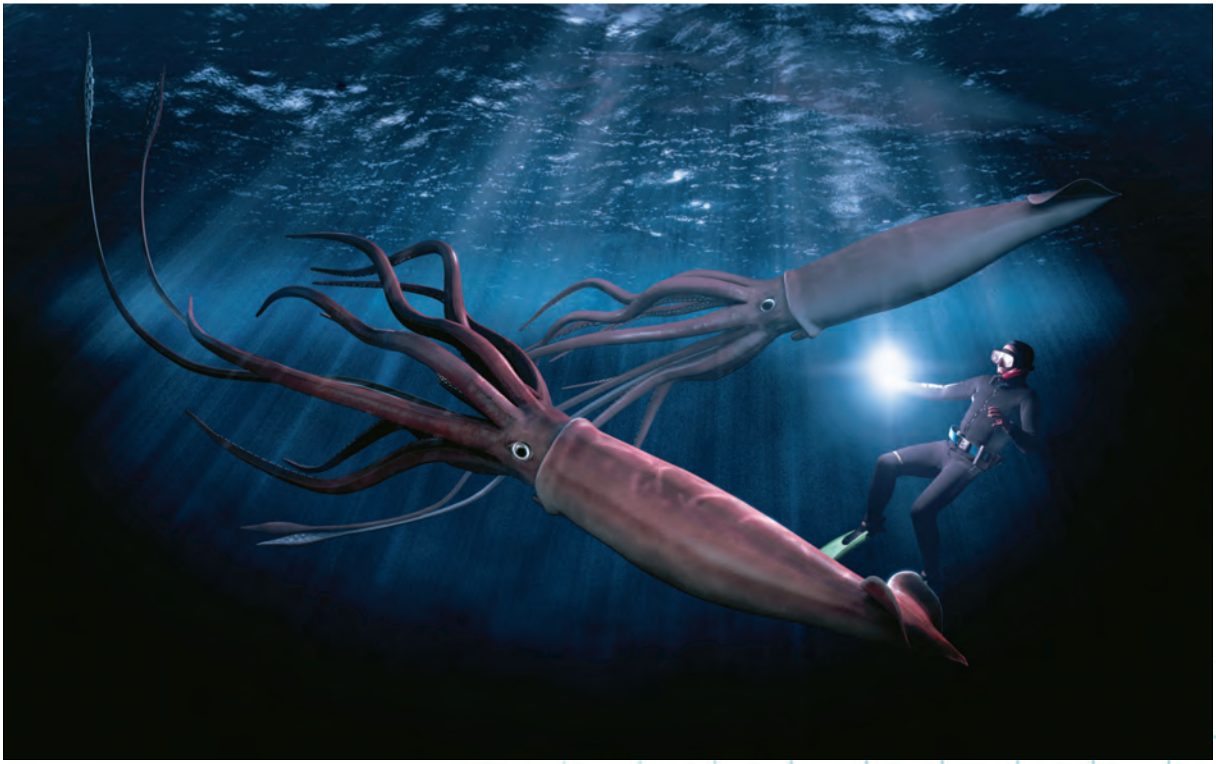
Although sharks do not have ears in the usual sense, their sharp hearing is extremely sensitive to irregular sounds, especially sounds made by wounded fish or an animal thrashing about. A narrow strip of sensory cells, called the lateral line, runs along their streamlined body and detects the vibrations of anything that moves. These pressure sensors allow sharks to feel sounds and vibrations.

An octopus has eight arms with suckers and more suckers surrounding its mouth. Each sucker has chemoreceptors allowing the octopus to taste and smell whatever it touches as it crawls along hunting for food. If it likes what it tastes, the suckers are used to capture the fish or shellfish or crabs. Inside the mouth poisonous salivary secretions paralyse the animal so the horny, parrot-like beak can tear the food into smaller pieces.

Situated just behind the mouth the doughnut-shaped brain wraps around the esophagus. With the esophagus running through the brain you could say that the octopus swallows its food through a hole in its brain!

Today observation, scientific study and knowledge has shown us that the octopus is a highly intelligent but shy creature with tricks that rivaled those of Harry Houdini.

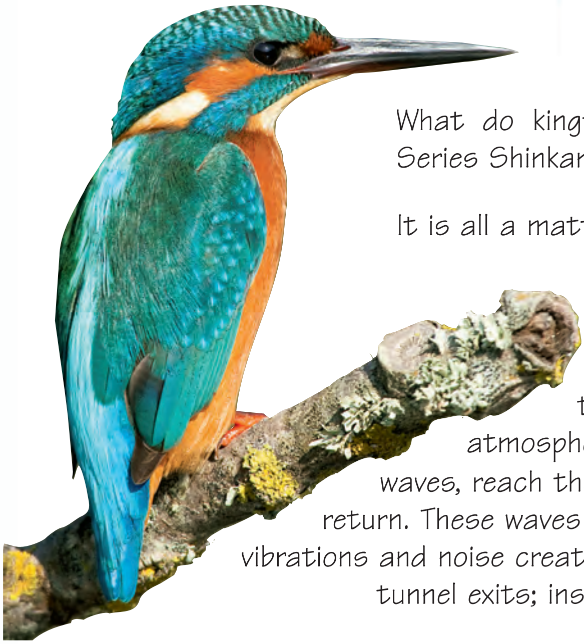
However, when early seafarers set out on voyages, they were sailing into uncharted waters where they believed sea monsters lurked. Tales of mythical creatures – the kraken, sea serpents, mermaids, devil fish, the hippocampus (giant sea horse), oversized lobsters that speared men with long antenna – appealed to the imagination and such stories were told and retold. The mythical devil fish (octopus) which attacked ships and dragged seamen to their watery graves was especially feared.



The relatively recent discovery of the giant and colossal squids in the waters around southern New Zealand and Antarctica perhaps explain how these stories of monsters from the deep arose. While not capable of wrapping up a ship in its long tentacles and dragging it to the bottom of the ocean, these enormous squid could well have given sailors of centuries past enough of a scare to create tales of terror that have been embellished over time.

Nature Thought of it First

High Speed Trains



What do kingfishers have to do with the high-speed 500 Series Shinkansen electric bullet train in Japan?

It is all a matter of aerodynamics.

Half the Shinkansen line consists of tunnel sections, and these sections presented the train designers with a problem. When a train rushes into a narrow tunnel at high speed, atmospheric pressure waves rise up, grow to be like tidal waves, reach the tunnel exit at the same sonic speed and then return. These waves are called tunnel micro-pressure waves and the vibrations and noise created environmental problems for people living near tunnel exits; inside the train the passengers were not affected.

Designers knew that the shape of the nose of the train affected the air resistance. They turned to nature to find the answer to the sudden changes in air resistance.

They studied the beak of the kingfisher!

The Shinkansen Series 500 bullet train.

When the kingfisher dives through low resistance air into high resistance water, it faces the same pressure wave problems as the train faced when going through the tunnel. On closer study, scientists observed that the upper and lower beaks of the kingfisher have an almost wedge shape – the ideal shape to suppress pressure waves. The kingfisher provided the answer to the train designers' problems. Using kingfisher technology, they designed a train with a long, wedge-shaped, bird-like nose. Copying the design of the kingfisher's beak allowed the bullet train to reach speeds of 300 kilometres per hour without creating noise or vibrations.

The New Zealand Torpedo

Long before the Italian-born physicist Alessandro Volta constructed the first device to produce an electric current, eels and catfish and rays were using pulses of electricity to stun their prey.

You may have heard of the South American electric eel or the African electric catfish, but right here in New Zealand's coastal waters we have the Electric Ray (*Torpedo fairchildi*), which belongs to a family of fish for which the self-propelled missile, the torpedo, was named.

This stunning, powerful ray has the ability to generate a series of strong electric charges of up to 50 volts. Its kidney shaped electric organs are situated on either side of its head and build up electrical charges in the same way as capacitors.

Torpedo rays are excellent swimmers and their circular disc-shaped bodies allow them to remain suspended in the water with little swimming effort, but they spend most of their time buried in sand waiting to detect passing prey. Then just like a policeman using a stun gun, the ray zaps dinner.

Torpedo rays are also called numbfish because of the practice of the Ancient Greeks who used electric rays to numb the pain of gout and headaches. This was recorded in 46 AD by a Roman physician.

Cement

The common barnacle lives in the wave-swept inter-tidal zone and to avoid being swept away by the strong currents, it secretes a rapidly curing, underwater cement that is one of the most powerful natural glues known to mankind.

Using Weight Belts For Survival

Sand Dollars – *Dendraster excentricus* – are highly specialised sea urchins that live on sandy beaches where they burrow into the sand to escape being washed away by water currents. The lunules or holes in their bodies help break up the hydrodynamic flow of water while these velvety-black cousins of the sea urchins pick through grains of sand with their tube feet selecting those with a golden brown film of diatoms.

The pale dead remains of the sand dollar is a more familiar find on our beaches.

It was Fu-Shiang Chia, a biologist, who discovered that juvenile sand dollars have a neat trick of building weight belts to keep them from getting washed away.

They select grains of sand containing high density magnetite which they store in special pouches in their intestine to provide the weight they need to keep them safe in a shifting sandy environment.

Did You Know...

Owls are able to fly silently down to grab an unsuspecting mouse or bird because their wings produce only small vortices when they fly. What is the secret of this silent flight?

The answer is the many small saw-toothed feathers in the plumes of their wings, which stick out from the outer rim of the primary feathers. These feathers are called serration and can be seen when you examine an owl's wing. Aerodynamic noise is a sound generated by vortices and is produced when birds flap their wings; the bigger the vortices, the more the noise increases. But the small saw-toothed projections on the wings of owls produce only small vortices, preventing the generation of noise.