Curiosity inspires, discovery reveals

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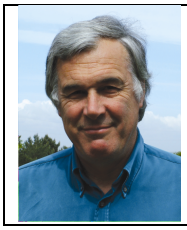

Tony is the co-founder and Editor in Chief of The Young Darwinian. He is an expert in bioluminescence, intracellular calcium as a universal signal, lactose and food intolerance, and Darwin. He has been involved in inspiring young people about science and natural history for over 30 years.

'I keep six honest men
(They taught me all I know);
Their names are What and Why and When
And How and Where and Who.'
Rudyard Kipling, Just So Stories (1902)

The beginning

Curiosity lies at the heart of our civilisation[1]. It fires the imagination, and creativity. In fact, without the discoveries and inventions arising from curiosity, there would be no civilisation. Curiosity about water, fire, plants and animals, the sky, and everything around us, triggered the first humans to produce the food they needed, new ways of cooking it, as well as materials and machines that enabled them to move objects, and defend themselves against attack or environmental change. The ability to select and develop crops, fruit, and

domesticated animals were founded on curiosity about the diversity seen in Nature, and then a realisation this could be exploited by focussed management.

Curiosity is one of the greatest gifts evolution has given us as a species. It is what singles us out from other animals. Yet it has been argued animals can actually be curious[2]. Many animals explore, in order to find food, to find a nesting site, for security, or to hibernate during winter. But, is this real curiosity? I would argue, no. There is a major difference between this animal behaviour and human curiosity. When humans explore, this triggers curiosity. This then raises questions – what, why, how etc. These questions then lead to discoveries. Curiosity inspires, discovery reveals. Animals do not follow this path.

In fact, wherever you are, whatever you are doing, there is always something to be curious about. Over 2 million years ago humans became curious about rocks, and what you could do with them. The first tools were invented. This was soon followed by curiosity about fire. How it could be started using wood or flints. How it could provide warmth at night, and be used to cook food, changing our diets forever. Yet, less than 10,000 years ago, a strange discovery was made. Milk carried in the stomach of a sheep or camel would curdle. Separating the solid curd from the liquid whey produced the first cheese. Dairying had begun. Rennet, a complex of enzymes from the stomachs of ruminant mammals, is still used today in cheese making. Soon after this discovery, people in the near East became curious about a brownish colour they found in some rocks. This was metallic copper, which they extracted using fire, allowing them to make utensils and weapons. The Romans obtained their copper from Cyprus, cyprium, which was corrupted to cuprum, leading to the chemical symbol Cu. Rocks, based on iron ore surrounding a fire, curiously, produced a silvery metal after the embers had died down. Carbon from the charcoal had reduced the Fe_2O_3 to Fe. The Iron Age had begun. At this time, a few thousand years ago, humans had only just learnt how to develop, and exploit, their invention of the wheel.

Curiosity leads the evolution of Western civilisation

The Greeks - Euclid, Pythagoras and Archimedes - some 600 and 200 BC, had an insatiable curiosity about shapes, pioneering the mathematical basis of geometry. This led to the remarkable discovery of π. But is the only reason we know that the circumference of every circle is $2\pi r$, and its area is πr^2, because our teacher told us. How did the Greeks work this out? And why is the circumference of an Egyptian pyramid divided by its height equal to 2π? Archimedes was curious about how you could prove a King's crown was made entirely of gold. This led to a fundamental discovery of how ships float. Amazingly, it was not until the 16th century, that the modern equals sign in mathematics was invented, by a Welshman, Robert Recorde (1512 – 1558). Curiosity about the internal structure of animals led other Greeks, such as

Hippocrates and Aristotle, two and half thousand years ago, to found the science of anatomy. Further afield, at the same time, the Chinese were puzzled about why bodies on a battlefield, a few nights after the battle, glowed in the dark. A similar glow is often seen on dead fish. Curiosity about this led, only 50 years ago, to one of the most important discoveries in microbiology – quorum sensing. Quorum sensing occurs when an organism responds to a stimulus generated by a population of living organisms. In the case of luminous bacteria, each tiny microbe releases a small amount of the stimulus compound. This builds up in the surrounding fluid. Once the concentration of the stimulus is sufficient to switch on the whole population of cells, a Rubicon is crossed. So the colony glows.

Yet it was not until the seventeenth century that curiosity was rekindled. For centuries, curiosity was often regarded as a sin[2]. Adam's sin in the Garden of Eden was not that he wanted sex, but that he was too curious about it! Humans had wondered what was in stars. And, in 1633, Galileo (1564 – 1642) was put under house arrest for nearly ten years after his 'Inquisition'. He was just too curious about the 'heavens'. Inventing the first really useful telescope, he proved that the Earth did indeed go round the sun, Heresy!! Galileo was also curious about how to determine one's exact location in longitude. He discovered he could use the moons of Saturn to work this out.

Fortunately for us, the curiosity of the first scientists and engineers in the seventeenth and eighteenth centuries was just too powerful. Antonie Philips van Leeuwenhoek (1632 – 1727) invented microscopy, discovering the most amazing things in pond and drain water, and even human sperm. His 'animalcules' (= 'tiny animals') were the first micro-organisms to be described. And, it was Robert Hooke who first used the word 'cell' to describe plant cells, that he saw in his microscope as being like a bee's honeycomb. The Royal Society, founded in 1660, brought amazing scientists and polymaths together. Hooke (1635 -1703), Boyle (1627 – 1691), and Newton (1643 – 1727) could now focus their curiosity, and argue amongst themselves whether they really had got it right. Boyle was very curious about gases, inventing an air pump, and discovering the relationship between pressure and volume of a gas – Boyle's law. Newton, on the other hand, was curious about how a rainbow formed, how sunlight was reflected off a lake, and why a straight stick looked bent when it was immersed in water. John Constable (1736 – 1837) missed this, when painting the cartwheel sitting in water in his famous 'Hay Wain'. Newton focussed his questions by carrying out some very imaginative experiments, measuring accurately the path of light beams, and the different colours produced by a prism. Eureka! He had discovered the laws of reflection and refraction, and the fact that the refractive index of each colour is different as sunlight passes through a raindrop. But how fast does light travel? Can it really flash around the Earth seven times a second. And why is it that the planet Mercury can be seen, even when it is actually behind the sun? Yes, as

Einstein (1879 – 1955) discovered, light can be bent by gravity. But is light a wave or particle? We still haven't sorted the answer to this question out properly.

From the 16th century onwards, explorers from Europe sailed all over the globe, curious about what they would find in far off lands. Christopher Columbus to the Americas, Francis Drake around the world, Walter Rayleigh to South America, Joseph Banks and James Cook on The Endeavour to Australia, Alexander Humboldt to Latin America, Charles Darwin on the Beagle, and Alfred Russel Wallace to the Amazon and the Malay Archipelego. These were just a few, who brought back extraordinary plants and animals for their fellow Europeans to marvel at. Many of these changed the diet and life style of our civilisation.

The 18th century was the Age of Enlightenment, full of musical, artist, literary, and scientific geniuses. Carl Linnaeus (1707 – 1778), in Uppsala Sweden, gave us a binomial system for classifying all living organisms, the foundation of taxonomy. Carl Scheele (1742 – 1781), in Sweden, and Joseph Priestley (1733 – 1804), in England, discovered a gas, named by Antoine-Laurent de Lavoisier in France as oxygène, just before he had his head chopped off! And Henry Cavendish (1731 – 1810) in England discovered that water was H_20. One unsung hero was Erasmus Darwin (1731 – 1802), one of Charles' grandfathers, and the best doctor in England. Erasmus was truly a polymath and genius, ever curious - about how clouds form, how the lightening conductor worked, that his friend Benjamin Franklin in the US had invented, what substances could be extracted from plants to treat the sick, and how life came exist at all. Yet he also saw that the discoveries of science, and the inventions of engineering, could benefit millions of people, if only their huge commercial potential could be realised. The Lunar Society, he founded in the English Midlands, catalysed the Industrial Revolution in Britain. Being able find your way home by moonlight, after a few drinks, was not the only achievement of this group! It was here James Watt enthused Matthew Bolton about his steam engine, which then came into the first British factory. Thus, entrepreneurship has been a vital part of the curiosity story, without which millions of people could never have benefited from the discoveries and inventions arising from science and engineering.

By the mid nineteenth century scientific curiosity was rampant. Humphry Davy (1778 – 1829) had the idea that atoms, in what we now call salts, could be separated using electricity. This led to him discovering potassium, sodium, calcium, and several other elements. On the other hand, his protégé, Michael Faraday, noticed a small flick of a needle on a meter, when he pulled a magnet out from inside a coil of wire. This led to the invention of the dynamo and electric motor, and then the light bulb. What would civilisation have done without these? The prediction of radio waves by Maxwell (1831 – 1879), followed in 1887 by their discovery by Hertz (1857 – 1894), has revolutionised communication. Louis Pasteur (1822 – 1895) is perhaps most famous for his discoveries about the fermentation of yeast and bacteria, leading to pasteurization, and the principles

of vaccination. Yet his curiosity about tartaric acid crystals on a wine cork, led to one of the most significant chemical discoveries in the nineteenth century. Molecules can be handed. They can have a mirror image. DNA uses right-handed sugars, and proteins left handed amino acids. Without this handedness, life would not exist.

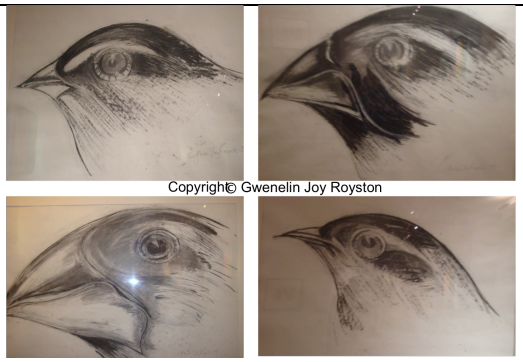

Figure 1. Why do these finches have different shaped beaks.
Each beak is adapted to a particular type of food, e.g. small insects or a type of seed. Darwin brought these back from the Galapagos. But, it wasn't until an expert ornithologist John Gould pointed out their uniqueness from each island, that Darwin realised how important they were to his big idea of Natural Selection. Peter and Rosemary Grant have shown, over 25 years working in the Galapagos, that Natural Selection is still working today on these beaks.

The word 'biology' was first used in the modern sense by a French scientist – Jean-Baptiste de Lamarck (1744 – 1829)[3]. He believed in evolution, but got it slightly wrong. He was curious about how giraffes got their long necks. He thought they got them by stretching up to high food, and this stretching was inherited by their offspring – the inheritance of acquired characteristics. A nice idea, but it was wrong. Instead, as Darwin and Wallace argued, the ancestors of giraffes had a range of neck lengths. The longer the neck, the better the food supply, and the more likely they were to survive to produce offspring, which would inherit this height characteristic. The animals Darwin found in the Galapagos archipelago gave him a eureka moment back home. The now-famous Galapagos finches aroused his curiosity (Figure 1).

Curiosity in the modern era

In spite of Darwin and Wallace, and their amazing discovery of Natural Selection, **the** unifying principle in biology, the nineteenth century was actually dominated by discoveries and inventions from curiosity about physics and chemistry. William Thomson, who became Lord Kelvin (1824 – 1907), realised there were three fundamental laws about energy – thermodynamics - and that you could never get enough energy to go below -273.15 ^{o}C, his absolute zero. Ohm (1789 -1854) obtained his PhD on one page, from curiosity about the

relationship between the voltage across a wire and the current through it. And, Henri Becquerel (1852 – 1908) discovered radioactivity, as a result of curiosity about why a photographic plate was apparently exposed to light from a radiation that could pass through solids. Throughout the nineteenth century curiosity about rocks, and the landscape, led to the science of geology, forming the basis of understanding how our planet evolved, and could be exploited. Mary Anning (1799 – 1847) exploded the Victorians' curiosity with the dinosaur bones she collected for Londoners from the blue lias in the cliffs of Lyme Regis in Dorset. And a curiosity about the chemistry of carbon led to the age of biochemistry in the twentieth century, showing that life was not dependent on a mythical 'vital force'. All animals, plants and microbes were simply chemical machines. The nineteenth century also saw a revolution in engineering, pioneered by engineers, such as Robert Stephenson (1803 -1908) and Isambard Kingdom Brunel (1806 – 1859), triggered by the curiosity of 'would it really work'? We saw the origin of the railway, the internal combustion engine, the beginnings of air flight, and steam ships.

The 20th century was an incredible success story for scientific curiosity, and the exploitation of the discoveries and inventions arising from it – planes, cars, antibiotics, genetic engineering, amazing medical diagnostics and surgical techniques, computers, the Hadron collider, and engineering feats – bridges, roads, and space travel - are just a few. All of these began with curiosity. In 1944, Avery and co-workers in New York, were curious about how a harmless bacterium could become a human pathogen by something transferred into it. This turned out to be DNA. They had discovered the universal molecule of inheritance. What was the genetic code within it, and how did it reproduce itself? The DNA revolution had begun!

Much of 20th century curiosity was for human good. But, sadly, the 20th century was also an era of much death from wars, fuelled by scientific invention. Now, in the 21st century, curiosity and imagination continue to inspire. Where would we be without curiosity about the physics and chemistry of silicon, leading to its brilliant exploitation by Bill Gates, Steve Jobs, Mark Zuckerberg, and Jeff Bezos who built Microsoft, Apple, Facebook,and Amazon? Indeed, where would we be without the Internet, invented by Tim Berners-Lee, and those who have inspired us to exploit it, such as Larry Page and Sergey Brin, founders of Google, Jerry Yang and David Filo, founders of Yahoo, and Jimmy Wales and Larry Sanger, founders of Wikipedia. What's more, this century has already seen amazing scientific discoveries, such as the Higgs Boson, medical breakthroughs in cancer, and space exploration. Yet, we still have so much to learn about ourselves, our natural environment, and the Universe.

My curiosity

My own curiosity began in the mountains and on the beaches in North Wales.

Cwm Idwal, Snowdonia,
North Wales

Figure 2. Why are there scratch marks on a rock on Snowdonia?
Darwin visited Idwal on his tour of North Wales, in August 1831, with his Cambridge mentor Adam Sedgwick. But he got it wrong. At that time, Darwin did not believe Idwal was glacial. But the Beagle voyage made Darwin an expert geologist. So he returned to Idwal, and realised that, in fact, it had been shaped by glaciers thousands of years ago, as shown by the scratch marks.

Why did some of the rocks in the Snowdonia mountains have scratch marks on them (Figure 2)? Why did the shells I collected on the Anglesey seashore have different shapes - helical, circular, spiral, flat, long, short, single, or bivalve? And why did the herring gulls, that flew off as I walked down the beach, have a red spot on their lower mandible? The Dutch biologist Niko Tinbergen (1907 – 1988) had already solved this. The red spot is the target for the chick in the nest, causing the adult to disgorge food when the chick's beak hits the spot. Tinbergen won the Nobel Prize in 1973 for this fundamental discovery about animal behaviour.

Then, wow, my first glow-worm! I had discovered bioluminescence – the emission of visible light from living organisms[3]. Was it physical, as Newton believed, or was it chemical? If it was chemical, as I believed, was there a commonality in the luminous animals that lived in the sea, the biggest ecosystem

on our planet? There are some extraordinary animals in the deep sea, arousing curiosity. Why, for example, are many of the shrimp that live there red (Figure 3)?

Figure 3. Why is this shrimp red?
In fact it is not red at all. It lives 1000 metres below the surface of the sea. Here the only light is blue, from bioluminescence. Shine blue light on what we see as a red object, and it will be black. So this is Nature's deepsea black pigment. Unfortunately for these shrimp, there is a group of deepsea fish – dragon fish - that have a large red-emitting light organ below each eye. Their eyes can see red light, but the shrimp cannot. So these fish have an invisible torch to light up their prey.

I was working in the medical school in Cardiff, at the time. What on earth had these luminous animals to do with understanding disease, or developing new diagnostic tests? I soon realised that a flash was better than a glow. This led me, with colleagues, to develop tests for cancer proteins, bacterial and viral infection, hormones, vitamins, drugs and many other substances in the blood, that were diagnostic of specific diseases. These tests are now used each year in several hundred million clinical tests worldwide, and created a multi-billion dollar market. In fact, amazingly, curiosity about fireflies and luminous jellyfish has created three individual billion dollar markets, with employment for thousands of scientists and ancillary workers worldwide. A further question that has dominated my research concerned the biology of calcium, not its familiar use in bones, teeth and shells, but its role inside cells. All cells do something when stimulated. A leg moves, a heart beats, a nerve fires, an insulin cell secretes, a sperm fertilises an egg, a jellyfish flashes, and a cell divides, defends itself or dies. All these cellular events are triggered by an external agent. But, what is the signal inside the cell that mediates this? Could it really be a simple cation – Ca^{2+}? The only way to satisfy this curiosity question was to measure the free Ca^{2+} inside living cells, and ideally in whole, live animals, plants and microbes[4]. Quite a challenge. I, and others, developed a way of doing this, using, first the protein, and then the DNA, from a luminous jellyfish. The light emitted from the live cells went up when the free Ca^{2+} went up, and down when the Ca^{2+} returned to normal. This universal chemical switch, inside cells, has revolutionised our

understanding of how life is turned on and off, and is the basis for understanding many diseases, and drugs to treat them. Yet it all started with curiosity about how a jellyfish flashes when you touch it.

Conclusions and The Young Darwinian

So this is a brief history of human time. Arguably, the most precious thing we have in our lives is what we do with our time. Following curiosity is a really good use of it. This article is just a skim through the curiosity of *Homo sapiens* over the last 3 million years[5]. But, I hope it will stimulate your curiosity, the starting point for any science project, and at the heart of The Young Darwinian. Let us know what you are curious about. We will develop this through Dr Darwin's Curiosity shop (see www.theyoungdarwinian.com), and catalyse the development of the skills of the naturalist in the spirit of Darwin – seeing, hearing, touching, smelling, tasting, and thinking. Let us know how much the curriculum in your country excites your curiosity. By the way, what is so special about the chemistry and physics of silicon that has revolutionised our lives?

As Erasmus Darwin once wrote over 200 years ago
'A fool is a person who has never done an experiment in their life.'

Bon chance and bon appétit.

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