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THE IDEA OF EVOLUTION

The oddest thing is that you're not quite the same person as you were a few seconds ago. You have a memory of picking up this book, and this memory has joined others held somewhere in your biology: how you came to be here today, who you are and even how to read these words.

Something must change amongst the atoms and molecules of your body for you to learn and remember these things. Learning, in other words, is transformative in a very concrete sense – it changes not just our mental world but also our biological form. Learning often accumulates so gradually and quietly that the changes go unnoticed. But some ideas are so profound they entirely alter a person's view of themselves and what's around them. And when that idea spreads, it can transform others until the world itself seems changed.

On 15 September 1834, the seeds of one such idea were waiting to be discovered – perhaps the biggest scientific idea of all. The theory of evolution would help us understand how the diverse abilities of species came about, including our transformative ability to learn. On this day, by a small volcanic island 200 miles off the coast of Ecuador, a rowing boat was launched from the HMS Beagle. Its occupants negotiated it along a treacherous and abrasive coastline. Eventually, the crew found a patch of black sand where their craft could avoid being scuppered. A young Charles Darwin stepped out onto San Cristobal Island, one of the *Encantada*, or enchanted isles (aka "The Galapagos"). These islands had been a foggy sanctuary for pirates raiding Spanish galleons and Darwin was also a treasure seeker – of a type. He was hunting specimens of local animals, but this island did not look promising. In his diary he wrote: "Nothing could be less inviting than the first appearance". He didn't know it then, but the treasures he was about to discover would play a critical role in solving the "mystery of mysteries": how life evolves, and how one species can become another.

The observations and specimens that Darwin amassed would help him launch the most influential and important theory of our time. And yet, Darwin was not a qualified scientist. Like many young men of his age, he had been pursuing leisure interests while postponing a "proper job", and he was especially fond of collecting beetles and bugs. He had dropped out of medical school and been pushed into clerical training in Cambridge in readiness for the Church – then the last resort for hopeless young men from good homes. His suitability for the Church was tainted by a dwindling faith and little interest in his studies but the consolation would be a rural parish with the time and opportunity to pursue his collecting. Fate, however, had something else in store. Cambridge led to regular contact and then friendship with a Botany professor called Henslow, with whom Darwin enjoyed many long rambles and collecting expeditions in the surrounding countryside. When Henslow turned down a trip on a survey ship called the Beagle, he suggested Darwin should go. Its captain, Fitzroy, mindful of his predecessor becoming severely depressed and shooting himself, was keen to find company for the two-year voyage ahead. The captain needed someone to eat with, someone who could engage in interesting conversation and keep his demons in check. A naturalist with the skills to collect some interesting specimens would, of course, be a bonus.

In 1836, after five years, Darwin arrived back from his voyage ecstatic to be once more at his father's home and amongst his sisters. Never again need he feel the seasickness that had followed him around the world. Within days, however, the family welcome had given way to a whirl of social and scientific engagements. His letters from abroad, giving reports of strange animals, breath-taking geology and fascinating peoples, had whetted the appetites of the intellectual and chattering classes. News of his return was spreading. His celebrity status meant dinner invitations, and the opportunity to regale and entice possible funders with his South American tales. While society events rarely excited Darwin, he knew that networking would be vital for establishing himself as a scientist. He would need help from those with scientific credentials, and he would need money, to ensure he could catalogue, research and exhibit his specimens. Between the dinners he toured the institutions where he might be allowed to unpack and place parts of his collection: the Linnaean and British Museum, and the scientific societies. At the Zoological Society, he presented 80 mammals and 450 birds, on the condition that they were mounted properly and described. Amongst these were the famous Darwin finches, although at the time Darwin thought they probably all fed together as the same species, and had no sense they had adapted to different environmental niches. At the Society, the "Superintendent" John Gould quickly perceived he was in possession of a new group of finches containing 12 different species. The media was contacted and Darwin's birds were set out for display. Within a few weeks, the discovery was paraded by the President of the Geological Society at a meeting where Darwin was elected onto its council. Darwin had been slow to understand he was collecting new species but, in fairness, what counts as a new species remains a subject of debate even today (see box overleaf). Now, however, this realisation stirred an all-important question in him: why is present and past life on any one spot so closely related?

Within 18 months, Darwin was married, financially independent and living off Gower Street in the centre of London. The massive task of cataloguing, describing and publishing his specimens had really only just begun, and here he was ideally placed close to the institutions and societies that could, if he kept them sweet, support his work. But he was already pondering other, more dangerous issues, ones he had to keep from his new scientific friends for fear of alienating them. Darwin's analysis of life's diversity on the Galapagos and its island-specific variation was confronting him with more inescapable questions, such as "Why, on these tiny islands so recently emerged from the sea, were so many beings created slightly different from their South American counterparts?" In 1837, he opened a secret notebook (the "B" notebook) and began to write his thoughts on transmutation – the changing of one species into another. According to his theory, new species were constantly being generated by evolution, rather than appearing randomly or via divine design. Darwin based his arguments on three observable

Speciation and extinction

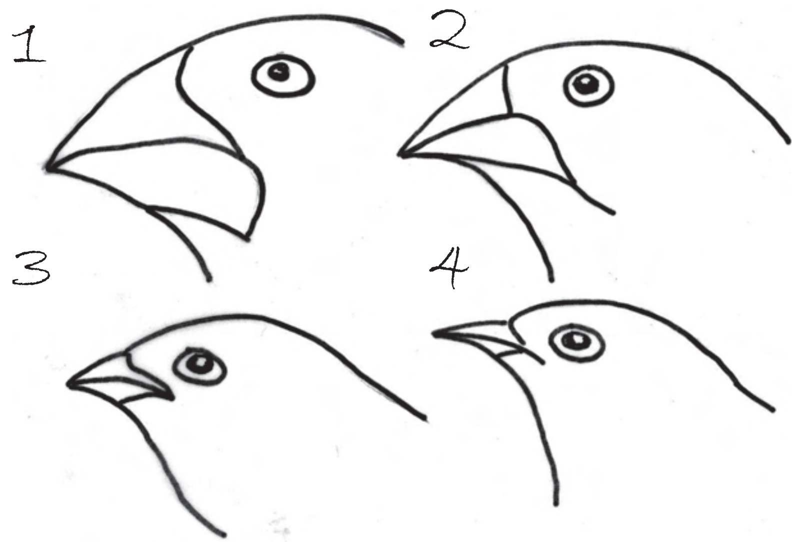
The concept of a species is a fuzzy one. When can we say there's enough difference between two evolving populations to claim we have two species? One widely used definition claims "speciation" has occurred when the two groups can no longer breed with each other.[1] Most commonly this happens when a significant number of the population becomes physically isolated due to migration or, as may have happened in the Galapagos, their habitat becomes fragmented. Within this smaller sample, inbreeding can result in a much faster rate of inherited change.

Since Darwin collected his finds on the Galapagos, small island-specific changes in its birds have been seen over just a few decades, as their environment has changed. Those birds who, simply due to random mutation, had beaks slightly more suited to the environment became naturally selected as a result.[2] Over a longer time, these changes can accumulate, explaining how different finch species have evolved and come to inhabit different islands, each adapted to the food supply offered by their island. For example, in these finches that were categorised by Gould, the beaks of 1 and 2 (opposite) are ideal for crushing large, hard seeds. While 3 has a beak ideal for grasping larger insects on the ground, 4, unlike these other finches, has the ability to catch and feed on flying insects.

When you think of the natural variation within humans, it doesn't seem so surprising that Darwin initially thought his finches were the same species. In addition to the normal variation within a species, another challenge of spotting species is that the "can only breed with each other" definition cannot apply to all life forms. It cannot, for example, apply to prokaryotes (single-celled organisms without a nucleus) since these do not reproduce sexually. These represent half the Earth's biomass and the great majority of its "species".

facts: 1) more offspring are produced than can survive; 2) trait differences between individuals influence their ability to survive and reproduce; and 3) these trait differences are heritable. On this basis, the argument follows that trait differences favouring greater fitness are more likely to be passed on, i.e. organisms evolve by a process of natural selection (see box on pp. 6–7).

But it would be another two decades before this idea was published. Why the delay? After all, you could argue the idea wasn't *that* new. In ancient Greece, philosophers had already disputed how easily and fluidly such transmutation might occur. Aristotle had suggested all living forms were variations on a defined set of fixed possibilities or "ideas". By the eighteenth century, notions of a fixed cosmic order had mostly vanished from scientific thinking about the physical world, but the living world was closer to



Compared with its beginning, defining the end of a species is much more straightforward. Almost all species known to have shared our planet are now extinct and it seems fair to assume that extinction is the fate of every species. Extinction occurs continuously but spikes have occurred in the background rate. The most dramatic on record was the Permian-Triassic extinction (252 Myr) when 96% of species disappeared. We are presently living (for the time being at least) through the Holocene extinction with rates 100–1000 times greater than background levels, with our own species implicated as the primary cause and global warming set to increase rates further.

the divine. Biology in Darwin's day still clung to notions of fixed natural types, created as part of some supernatural plan. This dominant notion of intelligent design had resisted suggestions by thinkers such as Lamarck that species might transmute. These "free-thinkers" included Darwin's grandfather Erasmus who, as a man of the Enlightenment, was contemptuous of the idea that God, rather than Nature, created the species. Erasmus was a renowned physician, lover of liberty, supporter of women's education and staunch opponent of slavery. But his family found many of his views concerning, since his unorthodoxy had gone further. Erasmus enjoyed writing erotic verse and prescribed sex for hypochondria, while his beliefs about evolution proposed "the strongest and most active animal should propagate the species, which should thence become improved". (That may explain

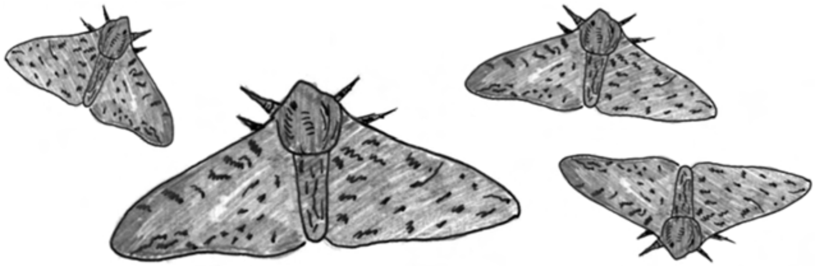
Natural selection

Though evolution tends to be slow and gradual, dramatic changes in the environment can bring about change more rapidly. The most famously observed example of Natural Selection is the pepper moth. Before 1811, only light-coloured pepper moths were known in the UK.

However, by 1848, at the end of the Industrial Revolution, a drastic increase in the dark-coloured variety was recorded around the industrial city of Manchester, where trees were often covered with soot. The Clean Air Act in the 1950s was followed by a decline in the number of dark relative to lighter-coloured pepper moths.[3]

why, in addition to the dozen children with his wives, he also had two with his children's governess.) In Darwin's family, evolutionary thinking was already associated with irreligious and immoral thoughts and behaviour – all threats to the status quo of respectable society. While Darwin remained uninterested in religion, his wife was devout in her faith and anxious about his ideas. Her anxiety worried him greatly.

Darwin knew that the damage potential for grand ideas about the origin of species extended well beyond his family. He was aware that evolutionary ideas can be exploited by both left- and right-wing politicians, much as they continue to be today. Since returning home, the gathering tumult in England was providing a lesson in the dangers. The Rev. Thomas Malthus had suggested that any population size, if unchecked, would grow exponentially and outpace the food supply. Darwin had made a similar observation in the natural world, i.e. that more offspring are produced than can normally survive. Malthus, however, made his own interpretation of this for policy – and had begun reflecting on what options should be implemented for checking population growth. He proposed not only that moral



Evolutionary theory prompted the idea that a light colour was more effective camouflage for these moths in a clean environment and a dark colour was a better way to survive predators when the environment became polluted.[4,5] Those moths whose colour was better fitted to their background survived and reproduced in greater numbers, and so that colour became predominant in the population. Understanding pepper moths from an evolutionary perspective helps us appreciate, understand and explore how they are "fitted" to their environment. It prompted further experiments that have confirmed the importance of colour for an individual moth's survival[6] and further questions about the genetics of moth colour.

restraints should be encouraged (e.g. sexual abstinence), but also that those suffering poverty and other circumstances he regarded as "defects" should not be allowed to reproduce. He promoted these policies as the available options to disease, starvation and war. On this basis, the poor did not need charity since this might expand their numbers; instead, they just needed control and discipline. Buoyed by Malthusian principles, the "New Poor Law" meant no more outdoor charity. Either the poor competed with everyone else or they would find themselves in the new workhouses that were springing up everywhere. Those outraged by inequities such as this "punishment of the poor" came together in a nation-wide protest movement (the Chartists) to support a people's charter. Riots ensued, soldiers were called out and some demonstrators were shot. One incident hemmed the Darwin family into their London home as troops charged crowds a few yards from their door.

A few days after those troop charges, in 1842, Darwin, along with his wife and children, retreated to a new and somewhat desolate home in the Kentish North Downs – far away from the chaos, unrest and noise of a restless London. This would be where Darwin could study and develop his theory in the solitude he now loved. Gone were the sounds of the Chartist riots in the streets below, but the thought of "coming out" with his ideas was still not attractive. He was no longer the naïve young man who had boarded the Beagle to pursue his hobby and avoid a job in the Church. If not picked up by Malthusians, his ideas might be adored by revolutionaries seeking to destroy the Church's power and disrupt the class structure his family benefited from. The Church's doctrine of God-given difference was key to its authority. It justified why some might be poor and powerless and others were rich and ruling. This underpinned the religious case for keeping things broadly as they were, protecting the wealthy Church and the elite that supported it. In contrast – Darwin's theory suggested all living creatures shared the same first ancestor – that we were all part of the same web of life. It dispensed with the notion of a divine decree that separated the human from the non-human, or indeed any type of human from any other. This sense of unity and its consequent equality would be a gift to those wanting to challenge the current order, and who were now taunting the Church as a "harlot" in bed with the state. The ideas spawning in Darwin's mind were contrary to his life as a pastor's son, his yearning for a quiet country life, the strong religious sentiments of his wife and the sentiments of his own social class.

The inner conflict all this created has been linked to the many illnesses that marred Darwin's life, and blamed for the incredible delay of 20 years in publishing his theory. Yet publish he did, finally prompted into a sense of urgency when Alfred Wallace sent him an essay proposing a very similar idea. There was now no point in holding back because Wallace would publish anyway. It is fortunate for all of us that Darwin stepped into the ring at this point to promote his theory with Wallace. The ensuing debate would need his unique skills and his massive body of evidence to ensure it was taken seriously and appropriately interpreted. His scientific rigour and humanism would help illuminate evolution as a concept that unified all humanity, and all life. After his long period of covert self-examination and agonising, he finally set the date for publicly committing himself. The event was to be a joint publication with Wallace, presented at the Linnean Society in Piccadilly.

In the end, the meeting itself was something of a non-event. Darwin had recently lost his youngest child to scarlet fever and stayed at home grief-stricken; Wallace was abroad. It was the final meeting before summer recess and a small audience of about 30 members listened without comment as the secretary of the society read out the paper. The President walked out of the meeting, lamenting how the year had been disappointing, with no "striking discoveries which at once revolutionize, so to speak, [our] department of science".

Ironically, perhaps, the lack of clamour had an encouraging effect on Darwin. He had now shown his colours and, despite all the anxiety, no-one seemed very bothered. About a year later, he published *On the Origin of Species*. Written for non-specialists, it quickly attracted comment from scientists and scholars, but also quickly ignited a mainstream interest. Darwin was amazed to hear stories about his book flying off the shelves at Waterloo Station as commuters passed through. The more popular the book became, the more difficult it was for the establishment to ignore. Passions were roused and arguments began to rage. The most famous of these debates occurred at a routine "Botany and Zoology" meeting on 30 June 1860, when a crowd of more than 700 crammed themselves into a chamber at the Oxford University Museum. With many more listening outside unable to get in, the audience watched as Bishop Samuel Wilberforce lost his argument against evolution to Darwin's friend and supporter Thomas Huxley.

Darwin on man's abilities

In the last few pages of *Origin of Species*, Darwin alluded to the significance of his theory for Homo sapiens and, most importantly, the mental abilities that many consider set us apart from the rest of the animal kingdom. Darwin suggested that knowledge of how mental abilities were prehistorically acquired (i.e. evolved) could provide fundamental insight into the nature of these abilities (i.e. our psychology):

> In the distant future I see open fields for far more important researches. Psychology will be based on a new foundation, that of the necessary acquirement of each mental power and capacity by gradation. Light will be thrown on the origin of man and his history.

Note how Darwin emphasised gradualism as an important feature of this process of change. Gradualism is an enduring theme of evolutionary thinking – the idea that evolution proceeds in very small microevolutionary steps in terms of adaptations within a population. These small but observable changes can occur much more rapidly than the sort of timescales usually associated with geological time. Speciation – the arrival of a new species – is generally assumed to take longer but comes about through the accumulation of these small changes.

Generally, however, *Origin of Species* steered clear of discussing our own place in the evolutionary tale. Darwin was still stepping forward cautiously and provided no clear indication of what the light he alluded to would reveal. Addressing this question would be a challenge of the greatest sensitivity. Darwin's time was even more human-centred than our own. Holding the belief that humans were related to animals was, even leaving religion aside, commonly seen as a serious step along a slippery slope towards barbarism.

It was not long before Darwin felt forced to tackle this issue directly. Once again, he was prompted by Wallace but not, this time, because their ideas were converging. Within five years[7] of co-publishing views aligned with each other, Wallace began to get cold feet about evolution, as discussion began turning towards Homo sapiens. He started to distance himself from the notion that human abilities might have arisen through natural selection. Wallace was asking his readers, "How could 'natural selection', or survival of the fittest in the struggle for existence, at all favour the development of mental powers so entirely removed from the material necessities of savage men?" Now – with the theory of natural selection itself at stake – Darwin didn't hold back on relating evolutionary theory to Homo sapiens and society. Darwin responded to the question asked by Wallace in *The Descent of Man, and Selection in Relation to Sex*. Published in 1871, this book included discussion of evolutionary ethics and the differences between races and sexes. After drawing attention to similarities in the anatomy of humans and other animals, Darwin found intellectual similarities as well. He saw evidence of emotions in non-human animals such as curiosity, courage, affection and shame – feelings that have cultural significance in society, and also the stirrings of features considered distinctly human such as tool use, language, an appreciation of beauty and even religious inclinations. In beginning to plot a continuum between human and animal mental ability, he argued for an evolutionary basis for the arrival of our own species.

In Darwin's time, physical features could be measured but evidence for how mental abilities evolved was much more limited. Even today, there's much debate around how to compare the mental abilities of different species. Nevertheless, Darwin had made an important point: the theory of evolution could and should be applied to help understand our own brain. The leap from understanding a pepper moth's wing to human reasoning and learning may seem great, but the principle remains essentially the same. Understanding the evolutionary history of the pepper moth allows us to ask questions and learn more about how the wing colour of an existing moth "fits", or not, the environment it finds itself in (see box on pp. 6–7). Similarly, an evolutionary perspective on the brain may allow us to ask questions and learn more about how a modern human brain interacts with its environment, including its educational environment.

Evolution gets hijacked by notions of "progress"

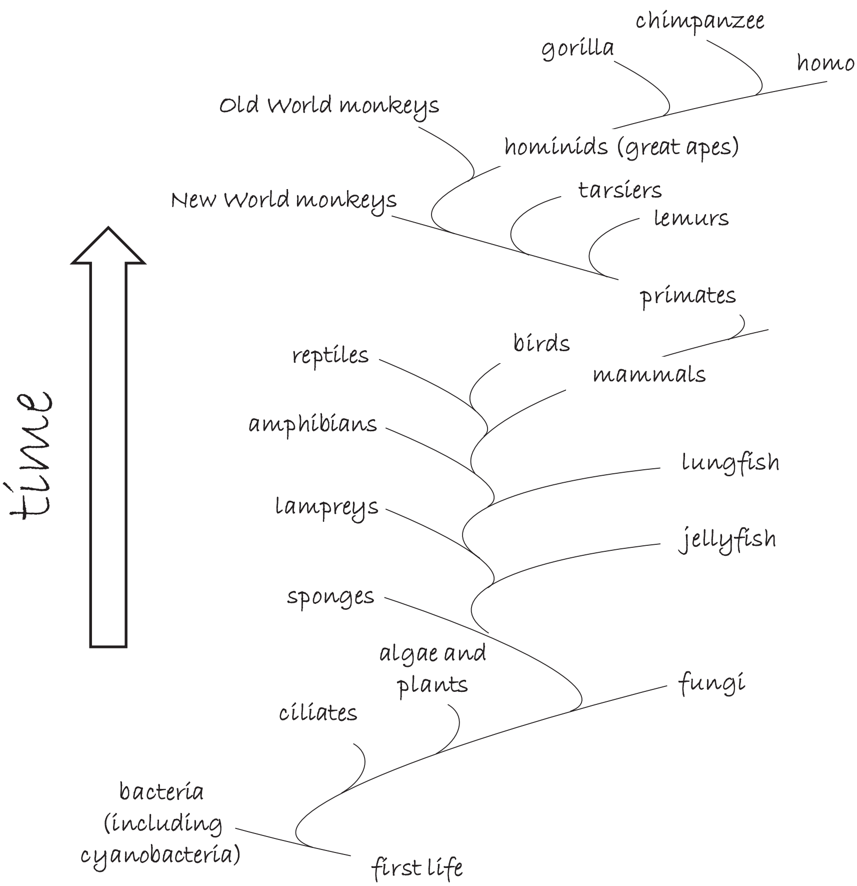
Only a decade after publishing *Origin*, Darwin's half-cousin Galton was already using it to argue for a science of "eugenics". In Galton's own words, this was meant "to give to the more suitable races or strains of blood a better chance of prevailing speedily over the less suitable". Galton was interested in ways to manipulate and accelerate the processes by which human evolution was progressing, improving the fitness of the species by *artificial selection*. From its outset, the very definition of eugenics was a dangerous mixture of skewed morality and misinterpretation of science. Competition, as in one line of organisms adaptively advancing in their populations over another, was an observable fact that reflected the proposed mechanisms of natural selection. However, Galton was suggesting some fixed direction of progress that could be artificially accelerated. This was not part of Darwin's theory.

There is debate about whether Darwin believed evolution generally tended in a direction of something that could be called progress.[7] He was, after all, a man of his time, and a rosy notion of progress was central to the ethos of the British Empire. That said, Darwin's understanding of "fitness" did not lend itself well to the idea and he never associated himself with Galton's proposals. His statement in a letter to American palaeontologist Alpheus Hyatt appears to make his views clear: "After long reflection, I cannot avoid the conviction that no innate tendency to progressive development exists".[8]

Tragically, however, many influential people have been seduced by the idea that we are evolving in some identifiable direction of biological improvement, and that there is some advantage in accelerating humanity along it. At the beginning of the last century, the idea of eugenics began gathering supporters in many countries, amongst them well-respected politicians such as Winston Churchill and prominent biologists such as Charles Davenport. At first, eugenics found application in some relatively innocuous ways, such as marriage counselling. Ultimately, however, it became manifest in Hitler's programmes of extermination, justifying the pursuit of "racial hygiene".

Eugenics is dangerous because it parades a human notion of "progress" (which is defined by whoever is doing the parading) as something biologically defined. Darwin's own diaries reveal a deep wariness of human notions of progress. During his travels, he had journeyed through lands in the New World where efficient programmes of genocide were being conducted. He found himself meeting face-to-face with characters who were linked to dubious military operations such as General Rosas in Argentina. These meetings were necessary to gain permission to cross land where indigenous peoples were being corralled into a "Christian's zoo", where the Indian women "who appear above twenty years old are massacred in cold blood". Rather than expressions of wonder at the specimens accumulating in the hold, Darwin's most powerful emotional responses were reserved for the atrocities that were occurring around him. Darwin's family strongly adhered to the belief that slavery should be abolished, but these sentiments brought him into sharp conflict with the Beagle's captain. Such experiences may have sensitised Darwin to how ideas about difference can be exploited, encouraging him to emphasise the message of life's unity he saw in evolution. Indeed, it has been suggested that political and social issues, particularly slavery, were key driving forces for Darwin pursuing evolutionary theory with such tenacity.[9] Evolution is concerned with how one form of life changes into another and so suggests, as it did to Darwin, that all life derives from a common ancestor. The idea we are all part of the same slowly shifting web of life undermines any sense of fundamental difference between races (i.e. variations) within the same species. More broadly than this, it connects all species with one another, highlighting the interrelatedness of all life (see the tree of life opposite).

Modern evolutionary theory takes care to separate evolution from cultural notions of growth and improvement,[10] and to discourage any perception of progress in one direction or another. The evolutionary meaning of the term "fitness" does not imply a score on any simple scale (i.e. speed, size, etc.), but refers to the extent to which an organism, over generations, has become suited or "fitted" to the environment. Given the environment is itself subject to constant change, it is perhaps unsurprising that evolutionary change sustained in *any* one direction over time tends to be the exception rather than the rule.[11] Natural selection has sometimes been summed up as "survival of the fittest", but in recent years scientists have come to prefer "survival of the fit enough". Evolution favours those equipped to survive, but there are few prizes (and likely some costs) for having more equipment than is strictly needed. Further limitations on any alleged scientific basis for eugenics come from our modern understanding of genetics and human ability. It seems unlikely that traits for skills such as literacy and maths could easily be artificially selected for, since the same genes, in different combinations, contribute to high and low levels of these



abilities. Nevertheless, we will see in Chapter 10 that modern science is making the idea of tinkering with human evolution much more possible.

The use of evolutionary theory to justify "scientific racism" has provided frightening examples of how science, authentic or otherwise, can be harnessed to seize moral authority when promoting ideas that are profoundly immoral. Eugenics remains a cautionary tale that reminds us of the importance of including ethical debate in the creation, interpretation and application of all science. Like many other powerful scientific ideas, evolutionary theory can be used for both good and evil, and how we use it should be informed by both science and by the views of those who might be affected. We will return to these issues again in Chapter 10.

Happily, modern evolutionary thinking has grandstanded more recently as a tool for encouraging racial tolerance rather than racial prejudice. South Africa is an example where this is particularly notable, since it was here that eugenics once played an influential role in supporting racist sentiment and justifying apartheid. In 1996, soon after the fall of the apartheid state, Mandela's government began to replace the old racially based system of education to reflect new values and principles for the country to aspire to. In the new curriculum, students would encounter concepts of evolution and particularly human evolution, so emphasising the common origin of humankind. The origin of humans from common ancestors was now perceived, as Darwin might have wished, as a strong unifying concept useful for building, rather than dividing, a racially diverse society.[12]

Evolution and genetics – the modern synthesis

Darwin's theory was founded on the idea that traits linked to survival and reproduction success could be inherited – and this fact could be clearly observed when he wrote and published his theory. But, in Darwin's day,

DNA and the processes by which traits are inherited

DNA is a very long molecule containing genetic instructions for the development, functioning and reproduction of an organism. It consists of two strands coiled around each other to form a double helix, divided up and packaged into separate pieces called chromosomes that are stored inside the nucleus of animal and plant cells.

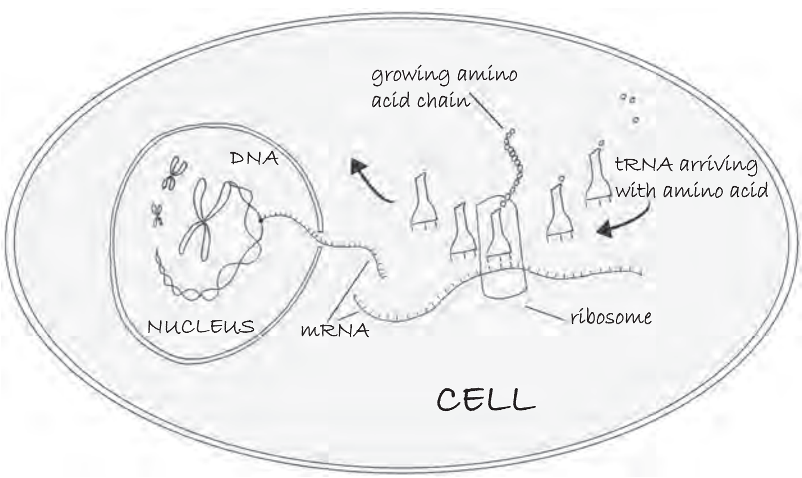
During the growth and repair of an organism, the DNA copies itself before the cell divides to produce another cell, allowing the new cell to have an exact copy of the DNA that was in the old cell.

Also in the chromosome is ribonucleic acid (RNA), which helps put the DNA instructions into practice. The instructions in the DNA code for how a cell should produce proteins. Proteins do most of the work in cells and are critical for the structure, function and regulation of the body's tissues and organs, including brain tissue. Ultimately, these proteins will generate the biological structures that help create the appearance and behaviour of the whole organism. A gene is a region of our DNA that codes instructions related to a trait. The most common human traits we think about (e.g. height and intelligence) are influenced by many such regions (i.e. they are polygenic). Traits are also, to a greater or lesser extent, influenced by environmental factors (e.g. nutrition and education).

Messenger RNA (mRNA) conveys the genetic information from the DNA to where molecular machines called ribosomes link amino acids together to no-one knew how such inheritance was happening. By 1865, Gregor Mendel published laws that showed how traits could be predictably inherited. Rediscovery of Mendel's ideas helped biologists in the 1930s to 1950s combine their observations with the new science of population genetics, creating the "modern synthesis", or "Neodarwinism". However, it was not until 1953 that the structure of deoxyribonucleic acid (DNA) and its role in storing genetic code were discovered, allowing the molecular processes of trait inheritance to finally be revealed (see box below).

By shedding light on the key process by which traits are inherited, modern genetics has supported the theory of evolution and helped us understand more about how it happens. For one thing, it seems clear that there must be sufficient genetic variation within a population for natural selection to work. This variation is essential for ensuring the presence of those with a markedly better fit, so enabling the traits associated with this fit to be selected. We now know the variation arises chiefly from the processes of

make the proteins. The amino acids are delivered by another type of RNA called transfer RNA (tRNA) but the order of linking is dictated by the mRNA, which follows the instructions it has carried from the DNA.



In sexual reproduction, DNA combines such that the offspring receive a novel mix of the DNA of their parents. This provides the genetic variation that makes evolution by natural selection possible.

genetic recombination which occur when organisms reproduce, but there are other factors contributing to this diversity too. These include processes of "mutation", in which a duplicate copy of an ancestral gene mutates and acquires a new function. This is not a very efficient source of improved fitness, because mutations appear more frequently to damage an organism than provide it with advantage. Even when competition and all else is equal, there will still be a small amount of randomness involved in how genes are transmitted across generations in a population. This "genetic drift" is another source of variation. These additional sources of variation are not adaptive in themselves: natural selection is still required for these changes to lead to improved fitness.

Natural selection is usually studied in terms of an organism surviving long enough to reproduce. However, sexual selection was also considered by Darwin as a process by which fitter traits might be selected for. Here, a mate is chosen for reproduction according to their fitness. The idea has a common-sense ring to it and feels credible, but concrete examples of sexual partners being chosen by fitness are only accumulating slowly.[13] Natural selection through being fit enough to survive, and so reproduce, remains the most widely applied theory of adaptation that improves the "fitness" of an organism, as coded in a population's genetic distribution.

Darwin, evolutionary theory and learning

There is a long history of evolution influencing educational thought. In 1881, Charles Darwin wrote a letter responding to the secretary of the Education Department of the American Social Science Association who had enquired about the significance of his theory for her area. In his letter, Darwin expresses his enthusiasm for understanding human development, and the need for research that could provide new insights. In his list of questions there is a sense that we should be concerned less with the objects of our children's attention, and more about the nature of their interaction with them. Darwin places emphasis on the importance of how the mental ability that underlies learning can be developed, rather than on the accumulation of specific knowledge and understanding. His ideas may reflect his own experience of pursuing his passion for collecting, in the face of little understanding from his father: "It may be more beneficial that a child should follow energetically some pursuit, of however trifling a nature, and thus acquire perseverance, than that he should be turned from it because of no future advantage to him".[14]

Perhaps, however, the most significant thing about Darwin's letter is that he doesn't provide specific suggestions on how we might teach and learn more effectively. Now a respected public figure, he had already expressed a very critical view of the school system, particularly its emphasis on the classics. He believed schools should broaden their curricula to include a greater range of subjects, notably science. When considering the relationship of evolutionary theory and education, Darwin did not use the opportunity to promote a list of changes that should be made. Instead, he believed his theory could be useful in identifying educationally relevant questions on human "mental and bodily development" and that these could prompt research that could produce educational insight. He seemed to be suggesting that educational change should arise from research that evolution can help frame, not directly from evolutionary theory itself.

Today this still seems wise advice – and perhaps timelier than ever. At this stage in the twenty-first century, we are just beginning to incorporate our new understanding of brain function and development into our ideas about how we teach and learn. Evolution cannot tell us how to teach and learn, but it can help us frame and understand this research. In this way, it can help us mentally digest the significance of our biology for revising our ideas about learning and the role of learning in who we are. Just as Darwin's theory prompted questions that helped us re-evaluate the relationship between a pepper moth's wing and the tree on which it rested, so the history of the learning brain may draw attention to new ways of thinking about learners and the environments in which they learn.

As the evolutionary story of the learning brain unfolds, you will see some familiar aspects of learning arriving over deep time. In each chapter, there will be some exploration of the links between these ancient processes and our own experience of learning as modern humans. Eventually we'll arrive in the present millennium and consider how the learning brain may evolve in the future. You'll have travelled several billion years by then and your own opinions about how we acquire knowledge and understanding may have changed – will human learning look different from a deep-time perspective? But enough jumping ahead; the story is about to begin . . .