Paper Reference(s)

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Edexcel GCE

Biology (Salters-Nuffield)

Advanced

Unit Test 6 Synoptic Paper

Scientific Article

June 2009

The first question in the synoptic paper will relate to the following scientific article, which you should study during your course.

You may be asked to summarise the information in the article, and explain or comment on the biology and issues within the context of the article.

The question will be worth 20 marks out of a total of 60 marks for the paper.

The article is adapted from the book *The Earth Only Endures* by Jules Pretty.

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Ecolution

One hundred and twenty years after Charles Darwin and Alfred Russel Wallace turned the world upside down, James Lovelock wondered, too, in his Gaia hypothesis, if the Earth had been shaped by life. The new believers wonder why they did not think of it first; the old disbelievers think it all utter nonsense, and sit back and wait. Years can pass before the new comes to be accepted. Max Planck famously once said, 'a new paradigm is often accepted not because it convinces the majority of its opponents, but because it outlives them'. Gaia remains controversial, mainly because some have misrepresented it as suggesting the Earth itself is alive. This was never the intention, but it remains an appealing idea to some searching for a guiding hand. What Lovelock did say was that life helped to make the Earth a place where life could persist. It made its own bed, and it's a comfortable one. At an average current temperature of 13°C (until climate change fully takes hold), the Earth is very hospitable. Mars and Venus, by contrast, are thoroughly inhospitable, one bitterly cold and the other twice as hot as an average oven. Life maintains the Earth's biogeochemical cycles far from equilibrium and this in turn helps to shape and influence the kinds of life that persist.

This makes the biosphere an emergent property of millions of years of interaction between life, the Earth and its environments. And we humans are part of this process too. Hominids emerged some 5 million years ago (our genus about 2.5 million years ago; our species about 160,000 years ago) and we have been shaped by hundreds of thousands of generations to arrive at where we are today. To paraphrase Sartre, all our lives have led us to this very moment. And here is the link back to Darwin, whose shattering idea of evolution driven by natural selection recognized the mechanism by which the many forms of life have emerged, survived and diverged in their specific environments. It is now clear that individual organisms, populations and their species change their environments, often in ways that increase their chances of survival. Survival of the fittest also means survival of those that influence their environments in a favourable way and can then pass on these capabilities to descendents.

At the same time as Darwin's *Origin of Species* was published, a monk in Austria was laying the foundations for modern genetics. Gregor Mendel's experiments with peas during the 1850s and 1860s clearly showed how characteristics, or traits, could be passed from one generation to another (though his work was not recognized until the early 20th century). A half century after this, Francis Crick, James Watson and the mostly forgotten Maurice Wilkins and Rosalind Franklin established the structure for DNA, which later allowed chromosome structure and gene expression to be determined. Another half century of huge collaborative efforts across laboratories in many countries has seen all the genes for a number of organisms fully mapped, including the 30,000 or so genes of humans. For a while, this appeared to suggest we are near to knowing everything about us and these other mapped organisms. But this is far from true. We know more, but also have gained insights into how little we still know.

Mapping and naming genes is like picking up the phone directory for your local town or city. Lots of names and numbers, structured in columns and helpfully all in alphabetical order. But from these lists alone, you can only guess about the structure and functioning of the city. You would need to ring up every person (or gene) and ask them what they do. You would then need to find out what causes that person to get up in the morning. What are their motivations? If it is a rainy day, will that person stay inside; if sunny, go to the beach? Will that person do something when another person (gene) in the phone book calls them and invites them over for tea, or was it to the pub? You may have one contact that calls every day, another only every five years. Today, we have a pretty good gene phone book and have begun to realize that we understand so little about how they interact – both with other genes and with the environments that are internal and external to the organisms which carry them.

This idea about having genes that need to be switched on before they act is beginning to entail some modifications as to how genetic and environmental processes are understood. We have all been taught (at least, we should have been) that traits are either dominant or recessive, that we have two copies carried on different strands of DNA and that inheritance is a pretty predictable game. And for some traits, it is. For blood groups, you can have an A or B gene, which are both dominant, but rare. If you have neither, you are O. If you have one A and one O, you are A. Chimpanzees, by the way, are either A or O, and gorillas are all B types. Thus we can see that you or I have genes for a particular trait. In short, a gene (or both) determines the outcome. Again, this is a simple and powerful idea, but it leads to many popular misconceptions about genetic discoveries. The gene for cancer, we are told, has been discovered. Or for left-handedness, or aggression, or divorce. And this is where the story begins to break down. Most traits, or outcomes, are shaped in very complex ways, and these driving influences can be both other genes and their products and signals in the internal and external environment. Genes do determine things, but they are in turn switched on and off by other things.

This, then, brings us to another enduring controversy: how much do genes or the environment affect who we are? Is it nature (genes) or nurture (environment or culture) that is mostly, or even solely, important? Like all supposedly handy dichotomies, the truth lies in elements of both, not one or the other. But the post-Darwin literature is often less forgiving. And this has led us into many difficult places. A century of polarised opinions seemed to explode in the mid-1970s with the publication of E O Wilson's *Sociobiology*, in which biological explanations were provided for many aspects of human behaviour and society. Many social scientists attacked Wilson, as did some evolutionary biologists. Part of the problem may have come from Wilson's provocative claim that the social sciences would eventually be subsumed into biology, as he indicated that a great deal of behaviour could be explained by biology alone. Even after the dust from this particular controversy has settled, there still remains a wide range of divergent views, from those who appear to reject any cultural explanation of human behaviour, to those memeticists who seek to provide evolutionary perspectives that are essentially cultural.

Even within evolutionary fields, there is considerable controversy and it remains hard to identify the relative roles of genes, the environment and human cultures on hominid and human development. Speculation and prejudice are common, probably because who and what we are actually does mean a lot to most of us. Inevitably, ideas get misrepresented, either accidentally or deliberately, in ways that suit some people's prior political, religious or even scientific interests. It is hard, therefore, to separate out biological fact, or indeed portion out the relative roles for biology and culture (or nature and nurture) in human evolution and our arrival to this point. Moreover, a great deal of discomfort about using genetic explanations for some aspects of human behaviour has arisen in reaction to those in the 19th and 20th centuries, who sought to use genetics to explain differences between races and between the rich and poor. To some, like Darwin's cousin, Francis Galton, this provided an opportunity to put all the differences between human groups down to heredity, and nothing to culture (through education or economic opportunity). Galton pioneered the study of twins, but also wanted to investigate 'the practicability of supplementing inefficient human stock by better strains ', as Matt Ridley has explained. These led to a position that suggests you have a set of genes passed to you, that these determine all that you are and that there is no role for choice (or free will). The slippery slide to eugenics had begun.

If evolutionary perspectives seem to explain so much about human behaviour and society, why are so many people hostile to these ideas – from the creationists and believers in intelligent design to the social scientists concerned about past uses of evolutionary theory to support certain political ideologies? Creationists cannot believe that the complexity we see in the world could have emerged as a result of evolution over millennia. And their opinions seem to be winning in some places – the 'new ignorance', as Steve Jones calls it. In the US, surveys seem to indicate that 40–50 per cent of people during the 1990s and early 2000s believed God created humans in their current form less than 10,000 years ago, 30–40 per cent believed humans developed over millions of years, but that God still guided the process, and only about 10 per cent believed humans developed from less advanced forms of life, with God having no part in the process. Of course, many people believe in one thing and act in contradictory ways. How many evolutionary sceptics, we might wonder, are quite content to have a flu jab that requires evolutionary understanding to develop and redevelop as the flu virus itself rapidly evolves? As Steve Jones also says, evolutionary stories are all around us, from dog and pigeon breeds to HIV – a retrovirus that is bad at making exact copies of itself, 'which is one reason why it does so well'.

One reason for these large numbers of evolution deniers (about a hundred million people in the US alone) is the enduring problem that evolution can appear to have direction. Things go from simple to complex, from worse to better, and at the end of the line, whether evolved or designed, are the humans (who are obviously the best). We should be very careful about the naturalistic fallacy of 'what is should be'. What we see now in the world, in human society, is not what should have happened. Nor is it the best, just because it is now. It is what emerged. As far as humans go, Neanderthals had an advanced and complex society and then disappeared. As for past civilizations, some 40 major ones have come and gone, lasting on average for 900 years, each of which probably thought itself to be the best just before the candles guttered out.

After Darwin, the concept of evolution as a linear and progressive force became widely adopted and remains with us today. Jean Lamarck erroneously believed in the inheritance of acquired characteristics and suggested that species strove to evolve greater complexity, thus the pinnacle of evolution had to be humans. Later, social Darwinism came to suggest that nature was more important than nurture, and that the development of individuals from birth to death (ontogeny) reflected closely the evolutionary development of species (phylogeny). Such ideas of progression (implying that the later is better, the more complex the cleverer), were later applied to human societies. Lewis Henry Morgan's *Ancient Society*, published in 1877, suggested seven stages of human cultural evolution, beginning with lower savagery and progressing through barbarism eventually to reach civilisation. The idea was that all human societies did share a common ancestor, but that some groups (or races) were now higher on the ladder than others. Such ideas fitted very well with prevailing views about the superiority of European and North American culture and again came to be widely accepted (though of course still hotly contested by many).

Setting aside the extreme religious views, the central problems that many people have with evolution and genetics centre on questions of instinct and free will (which, in the light of what we now know about genes, are probably false assumptions anyway). Ethologists, like Nikolaas Tinbergen and Konrad Lorenz showed clearly that many animals and birds responded to cues in very predictable and deterministic ways. Instinct, it would appear, was critical. But instinct implies no thought – it is something an animal, or you, do, driven only by your genes. This is already troubling, especially to those who base their philosophical and political ideas on those of, among others, John Stuart Mill, who indicated that the mind at birth was empty and is gradually filled as we experience the world, implying that we have the ability to choose these experiences and so shape our own lives.

Before E O Wilson, others took a similar line, such as Desmond Morris in *The Naked Ape*, whose hugely popular book suggested that modern humans were shaped in the Stone Age, and that most of our behaviour was explained by reference to those conditions. This has wide resonance, but Morris also treated humans as if current culture played second fiddle to genes. The problem, as in so much of the history of evolutionary thought, is that some people cannot resist slipping into language that says what they believe is right and wrong, or better and worse, rather than explaining what happened or might occur in the future. Evolution does not have a directing hand, or a determined pathway. It is about adaptation to environments, changing environments to make them more suitable and the survival of those genes (and the organisms that carry them) that are best able to do these things.

As we shall see, genes play a fundamental role in shaping who and what we are, but they do not act in a vacuum. They take their signals from the environment, which once was predominantly ecological but now is cultural too, and these signals switch them on and off. What we are is actually an emergent property of both genes and ecological-social environments, and thus we do have choice. We cannot bend our genes to our intentionality, at least not personally, but we can and do affect the environment which indirectly presses our genetic buttons. Thus, as Kevin Laland and Gillian Brown say, 'using evolutionary theory is not the same as taking a genetic determinist viewpoint'. Indeed, says Richard Dawkins, 'the bogey of genetic determinism needs to be laid to rest'.

Decades of binary controversy over either nature or nurture should now lead us to the sensible conclusion that neither alone is explanatory. Both are important. This will annoy both those who have come to believe that culture is predominant and those who would believe that genetics can explain all. It is not my intention here to review all the science behind the many different strands of evolutionary theory (including sociobiology, evolutionary psychology, human behavioural ecology, memetics, gene–culture coevolution and evolutionary anthropology). But what is common to all is the idea that hominids evolved over millions of years, that we spent a long time becoming adapted to environments of our ancestors (as are all organisms), that many complex aspects of culture emerged fairly recently (50,000 to 100,000 years ago) and that the ecological and social environment played a role in influencing which genes succeeded and were passed to later generations.

The controversy over how much genes or the environment affect who we are is curious, as we pretty well accept the fact that genes are units of inheritance. Genes determine a great deal, but strangely we do not seem to find this a comfort. The problem centres on questions of free will, which we would all like to think we have. I am free to choose what I think or like, I am free to be happy or sad, or to choose one person or food over another. I can choose, in other words, my own future. It is not, though, that simple. Genes shape those choices, as we do our environments, which once had antelopes in them, but now have supermarkets and fast food outlets. And how much free will do we actually have when it comes to buying food? Are we not subliminally influenced by advertising anyway? Do the stores not seek to influence your choices in subtle ways? Of course they do. The average American child will have seen 360,000 TV advertisements and 200,000 violent acts by the age of 18.

Both genetic determinism and the idea of being born with a blank slate are wrong. None of the commonly used binary oppositions – genes or environment, nature or nurture, innate or acquired, individuals or culture – are alone correct. The problem is that false insights into these questions have led to the expression of many political and social prejudices, and in the hands of tyrannical leaders allowed many atrocities to be justified. Some believed they could, and should, create a master race (as if the environment did not matter), others that they could rewrite human nature if social circumstances were changed (as if genes did not matter), though most, it is true, have not occupied such extreme territory. The worries about genetic determinism, though, are centred on false ideas about genetics. As Matt Ridley has rightly put it, genes are not gods. Just because you or I have a particular gene does not mean it will necessarily be expressed (it may sit quietly doing nothing); equally, if we lack a certain gene, it does not mean we will lack a trait or characteristic (another gene may step in and do the job instead). As Ridley rightly says:

> *genes spend just as much of their time responding to our actions as they do causing them. Genes do not constrain human freedom, they enable it.*

The central dogma of genetics has long been that information flows out of the gene, not back to it. Experience (the environment) does not change gene sequences (DNA), otherwise Lamarck would be correct. But information does flow back to genes to affect their expression. Genes are switched on and off by signals from the environment. These signals can be transcription factors (themselves encoded by genes) that bind to the promoter sequences of genes, or a range of other molecules, such as proteins, that transmit external environmental cues into some form of internal signal. For example, the 17CREB genes are part of the mechanism of learning and memory. If one of them does not work, then long-term memory cannot form. These genes alter the connections between nerves and are switched on when the brain lays down new memories. If you create no new memories, then these genes will not be used. The act of learning turns on these genes, and learning is affected by what we do as whole organisms in our environments.

Each of us carries our own phone-book set of genes, but not all of them are expressed in a lifetime. It depends on the external and internal signals that switch genes on and off. One example is the changing of skin colour. Over time, pale-skinned people living in environments with plenty of sunshine will become dark skinned. This is not because they acquire this characteristic and then pass it on to their children. It is because melanin production in the skin is very sensitive to exposure to sunlight. Sunlight switches on genes that individuals might have carried for their lifetime without expression (had they stayed out of the sun). Descendents have the same sets of genes, but they are switched on early in life, producing darker skin. Over time, whole populations living in sunny places will become dark skinned.

Philosopher Daniel Dennett has called the concern about genes and free will ‘the panic that lies underneath the surface’. Are we fully responsible for our actions? We may more often come to hear the cry ‘it’s not my fault, it’s the fault of my genes’. Indeed, this has already happened in the US, where in 1994 the lawyers for a convicted murderer, Stephen Mobley, argued in his appeal that he came from a long line of criminals and that he committed murder because his genes made him do it. In short, he wanted to pretend he had no free will. This raises more fundamental philosophical questions. People generally want to be responsible, want to have the choices to avoid a behaviour that may be coded for by a particular set of genes. Yet knowing about how genes and the environment interact could actually increase free will, not constrain it further, as some people worry. Ridley argues that ‘knowing you have an instinct makes it possible that you will decide to override that instinct’. When we know that certain genes are associated with certain kinds of behaviour, it does not mean that someone with that gene is locked into a certain and inevitable pathway. They still have choices. We rewrite ourselves as we grow.

Organisms do not evolve in a static environment. They are constantly changing it, and therefore changing the course of their own evolution. This is what Kevin Laland and John Odling-Smee have called 'niche construction'. Organisms modify the environment and so modify the sources of natural selection too (often to make them more favourable). All organisms constantly interact with their local environments, and so change them over time. Earthworms change the structure and chemical composition of soils by dragging leaves and other organic matter into the soil, thus mixing organic with inorganic materials. Thus 'contemporary earthworms live in worlds that have been partly niche-constructed by many generations of ancestors'. Other niche modification examples include elephants that uproot whole trees, open canopies, create parkland and recycle the herbage through their bodies, which in turn reduces the incidence of fires. Hippos create close-cropped riverside grasslands and, as large browsers, trample vegetation and keep the understorey open. Wild boar create open ground and aid tree germination, and beavers form riverside water meadows and coppice willows. Thousands of spectacled eider duck assemble on the Arctic Sea during winter, keeping the sea ice open through their continuous movement on the surface, so allowing them to dive down 60 metres to get food throughout the winter.

The idea of niche construction is similar to Dawkins' idea of the extended phenotype. Genes build environmental states beyond the organism to increase their chance of survival. Some extended phenotypes can be inherited, if the environment is changed, and benefit future generations, which then continue to maintain the environment in a favourable state. Ecological inheritance does not depend on just biological replicators (genes), but on the persistence of physical changes too. Organisms modify environmental resources. They effectively try to change their worlds to make them more favourable to their own survival. Laland and Odling-Smee suggest that organisms shape environments as surely as environments shape organisms, with the result that 'evolution is transformed from a linear to a cyclic process'.

But Odling-Smee and Laland also suggest another concept – that of negative niche construction, when organisms destroy their habitats. Could we humans be driving ourselves to extinction by harming the very environments in which we evolved so successfully? It is now an increasingly common conception that humans are well adapted to the ancestral Pleistocene environment, but not particularly to the industrialized environment. But this is only partly correct. Foundations were indeed laid in the Pleistocene, but evolution has been working since then. We have also been modifying the later environments, and these must have been having an effect on us too. Niche construction also suggests that the initial environment of savannahs was in the first place shaped by hominids. We did not simply evolve in one environment and then stop. We continued to change.

Time, though, is a key factor. We spent many thousands of generations in the savannahs before moving out across the world some 100,000 years ago, and so many design solutions of that time could be expected to have persisted to today. During most of our history, natural selection was the key determinant of who survived to pass on their genes – presumably those of us who jumped the furthest when the scimitar-toothed cat leapt, or those who knew where to find or catch food. Later, more complex components of culture came to play an important role, with the richest and most powerful having the resources to ensure their progeny survived best. Only recently, however, has culture come to dominate and build a new environment that is increasingly hostile to the genes we carry.

For most of our time, in other words, we have survived in a world rich in biological diversity. We have, of course, been part of this diversity, shaping it and being shaped in return. We change the environment – burn the grasses to prevent scrub encroachment, channel the water to trees, collect the fish with care – and it shapes us. The natural environment is not a fixed entity that does not change over time. We amend it and the environment affects which of us will survive. But if the shaping is harmful, does this mean we eventually harm ourselves? Are humans now, by causing massive species extinctions and changing the global climate, actually threatening the survival of modern civilisation? And it would be good to know now, as it might still be possible to do something about it.

Ancestral humans did clearly play a significant role in reducing biological diversity before this generation's extraordinary extinctions. We hunted the mammoths to extinction in Europe, the ground sloths in the Americas and the slow-moving ground marsupials in Australia. But nothing compares with today's losses – called by many, the sixth great extinction. The previous five were all caused by global geological or climatic catastrophes. This one is being provoked by humans alone.

One question might be, then, 'Are we still evolving?' Many would like to believe that human evolution stopped some 50,000 years ago, before races and groups diverged. But recent research on single nucleotide polymorphisms (SNPs) has shown that many versions of the same gene (called alleles) have evolved during the past 10,000 years. Genes known to be evolving include those for skin colour, skeletal development, hair formation, food metabolism (especially leptin control) and susceptibility to Alzheimer's disease. Bruce Lahn of the University of Chicago discovered a gene called microcephalin that emerged 14,000–60,000 years ago and is carried by 70 per cent of us, and another, ASPM, which is carried by a quarter of the world's population, even though it emerged only 500–14,000 years ago. If we are still evolving, then this may paint a different picture for how the future may unfold.

Another example is language acquisition. On chromosome 7, the forkhead box P2 gene (or FOXP2) codes for a transcription factor (switch for other genes) which, when broken, leads to severe language impairment. FOXP2 is necessary for the development of normal grammatical and speaking ability. In all mammals (including mice, chimps and humans), the gene is the same. But since humans and chimpanzees split, there have been two very small changes to the protein products. One mutation substitutes a serine molecule for an arginine at the 325th (of 715) position in the protein. The mutation appeared about 200,000 years ago and was so successful that it quickly came to dominate in all human populations. Humans and higher apes use completely different parts of the brain to produce calls compared with those that humans now use for language. This language centre is on the left side of the brain in a part of the motor region used for gestures.

A variety of other human traits have emerged as a result of recent evolution. These include the increase in myopia following the invention of spectacles, the spread of the ability to digest milk sugars after the invention of dairy farming, and the extension of our physical abilities without having to get bigger muscles after the invention of stone tools. We are now changing our environments even more and these changes will inevitably have some influence on future human evolution. This raises a variety of interesting questions. What types of environments shape which genes? Which environments are better for us and which worse? What is the effect of certain environments on our health? Moreover, what is it to be human, when so many of our genes are shared in identical fashion with other organisms? For example, the difference between two humans is 0.1 per cent of the genome (3 million base pairs); it is 1.5 per cent between a human and a chimpanzee (45 million base pairs). Humans and chimpanzees have some 30,000 genes, with only 450 differences. We also now know that the genetic variation between human populations is small compared with the differences within populations.

A good reason to be humble about our hominid status is the striking uniformity across species when it comes to genes. Humans share 3000 of our 30,000 genes with the fruit fly and round worm. We also share 1000 genes with unicellular yeast and 500 with bacteria (these are universal to all living things as they mediate DNA, RNA and protein links). Many of our genes and development pathways are thus shared with other organisms. For example, the hox (homeotic) genes lay down the body plan and work in identical fashion in flies, frogs and fish as well as us. As they are shared widely across species, the clear evolutionary implication is that these organisms share a common ancestor. We now know that one gene can do different jobs at different times and different genes can do the same job. Thus the presence or absence of a particular gene does not guarantee the presence or absence of a particular trait. It may do; it may not. It will depend on transcription factors and how they switch genes on and off. The Eve gene in fruit flies is switched on ten times in a fly's lifetime. It has 8 promoters and each promoter requires 10–15 transcription factors to switch it on. Thus a small number of genes can interact in very complex ways to do different jobs.

How, then, do some of these interactions occur? It is now known that early activities can change us for life. The behaviour of mother rats can influences the expression of genes in their offspring. If young pups are not licked and groomed, then methyl groups are added to the DNA of a receptor gene expressed in the hippocampus of the brain. This gene normally helps to mediate responses to stress, but when methylated, rat pups produce higher levels of stress hormones and are less confident in new environments. The effects last for life. Moshe Szyf and colleagues at McGill University in Montreal found that a common amino acid and food supplement, L-methionine, has a similar effect in adults: it methylates the gene and makes people more stressed. In theory it should be possible to find compounds that demethylate, though the problem is that most such compounds do many jobs and it may be very difficult to predict wider and unintended effects (methylation is not all bad – it helps to shut down human endogenous retroviruses that are inserted into our genes). We may find that a walk in the country acts in an equally good way to reduce stress.

Sarah Hardy, at University of California at Davis, believes that the way modern adults are rearing their children is likely to have long-term emotional effects. Society may be becoming less empathetic, especially as fewer people live in extended families. It is known, for example, that men who spend time with infants have lower testosterone levels. Without families or mixed communities, this natural control over high-octane behaviour is lost. In one-year-old children, the higher the testosterone level, the less eye contact is made by the baby with the mother. Females seem to have more interest than males in faces, and this gradually forms into a preference for social relationships. There are also other predictors. The more testosterone in the womb, the longer the ring finger of the embryo, as the hox genes that control the growth of genitals also control digit size. Men with long ring fingers have a greater risk of autism, dyslexia, stammering and immune dysfunction and have more sons. But men with very short fingers are at greater risk of heart disease and infertility. Like all of these types of correlation, though, it is very difficult to be clear about causality.

Some genes are also known to shape components of personality. The gene for brain-derived necrotrophic factor (BDNF) is on chromosome 11 and is a short gene of 1335 base pairs. The protein it produces encourages the growth of neurons in the brain. In three-quarters of humans, the 192nd letter is G; in a quarter, it is A. The G causes a methionine amino acid to be put in the 66th position on the protein; the A puts in valine instead. As we all have two copies of each gene, there are three kinds of people: met–met, who are likely to be the least neurotic, met–val, who tend to be intermediate, and val–val, who are the most neurotic. But, again, it does not mean we are stuck with these labels with no choice. We can still decide to behave in different ways. Owen Flanagan of Duke University has found that Buddhists who practise meditation have significantly increased activity in their left prefrontal lobes, indicating positive emotions and good mood (the right prefrontal lobe is for negative emotions). But Buddhists are not born happy. They develop the characteristic by learning and practised behaviour. Buddhist training also seems to change the way the brain responds to other stimuli. As a result of their distinct pasts, they are much less likely to be shocked, surprised or angry.

As knowledge of gene function increases, many new questions are raised about environmental influences. It is now known that weight is partially heritable: the correlation in weight between identical twins is 80 per cent, against only 43 per cent between fraternal twins. Thus, given the same access to food, some people will put on more weight than others. Food shortages during pregnancy change the likelihood of the embryo suffering from obesity in later life. A poorly nourished embryo is born expecting to live in a state of food deprivation throughout its life. Its metabolism is geared to being small and is good for hoarding calories and avoiding excessive exercise. If this individual finds itself with plenty of food all the time, then it responds by growing rapidly, putting on weight and straining its heart. If there is famine in the first two trimesters, then babies with normal birth weight themselves give birth to small babies. On the savannah and other locations where food is sometimes scarce, they survive. In cities populated with junk food outlets, they will not.

Genes and the environment shape IQ too. In studies of 350 pairs of twins, it was found that virtually all the IQ variability among the poorest group was accounted for by the environment and not genetic type. Among the richest, the opposite was true. Thus raising the safety net of the poorest does more to equalise opportunity than reducing inequality among the middle classes. Ironically, too, the more equal we make society and the environment, in other words the less wealth and background matter, the more genes define differences between us.

Ever since the earliest hominids stepped into the savannahs, some 250,000–350,000 generations ago, a dance of genetics and culture has determined which genes have survived to reach us today. In some circumstances, the fittest have survived – those that caused their bodies to run the furthest when prey needed chasing down. In others, the richest or most powerful survived – those with the resources to ensure their progeny survived best. It is the poorest who are more likely to suffer high levels of infant mortality; it is the richest who are more likely to pay their way out of a problem – buying clean water rather than relying on sewage-contaminated ponds. The balance between biology and culture changes through human history, but will it change again? What will the future bring? There are two certainties: environmental destruction will continue for some time, perhaps the whole of this century, and, at the same time, medical and biological technology will transform us internally, perhaps even bringing mergers with silicon technology to produce new cyborgs. We may bring on an age of destruction and an age of isolation at the same time.

When great civilisations fall, for whatever reasons, who among their people are most likely to survive? No longer does a particular bundle of cultural values or symbols of economic power guarantee survival. Indeed, those most likely to survive will be making a living without relying on the large infrastructure and institutions of a dominant civilisation. They will survive if they can grow and collect their own food, if they have families and neighbours who can work collectively, if they have the knowledge and skills to make a local livelihood. But is the inevitable outcome of our current civilisation to charge towards the precipice with our eyes closed, damaging the very environments that produced us? Will modern globalized society become number 41 on the list of departed civilisations? Or might there come another phase in human history, where we recognise the critical importance of the environment in making us who we are, and appreciate that harm to this world harms us too? Such a new phase may rely equally and intelligently on a mix of evolutionary and environmentally sensitive cultural influences. But is there any possibility of a further phase of human history centred on survival of the greenest, a process we might call ‘ecolution’?

For ecolution to happen, it is going to take some pretty big leaps of imagination. We will need to recognize that green places are important to us and then look after them. We will need to be more humble about ourselves and step off the comfortable plinths. 'There is nothing', as Laland and Brown have put it, 'about natural selection that supports a progression of population towards an end goal or higher state.' We will have to have a sensible adult debate about genetics and free will. And we will have to ask some tough questions about what it is we want to sustain. As David Orr asks, do we wish to preserve an 'intimate relation with nature or total mastery'? Do we want to preserve an ever richer world, but one that can only become richer by converting natural resources to monetary values, and also by increasing the gap between the poorest and richest? Or is their another way?

Natural selection produces diversity, but only because a variety of environments or conditions means that a range of genes are required. If the environment becomes a monoculture, then inevitably a more limited set of genes will be selected. Monocultures are not just bad because they are not diverse. They undermine the fundamental nature of the biological world itself. Today's industrialised processes have often come to mean a desire for homogenisation. Yet a diversity of environments, or opportunities, drives evolution, so not only are we destroying species through habitat destruction, we are undermining the likelihood of the persistence of the world as we know it. Evolution increases information content and increases intelligence. Will ecolution continue these processes after our current age of destruction – of biodiversity, of nature, of languages and communities, of stories? Good communities are places where imagination grows and memories persist. Does imagination, like intelligence, grow over time? And has it now stopped growing in the modern age? Has, in other words, normal evolution been put on hold (while we destroy and are destroyed)?

The key to ecolution is imagination, knowledge and interest; the same thing, time after time, no longer keeps us interested and we become bored. The modern homogenised world has reduced our understanding of the natural world, our daily connections, our capacities and desires to care. It is true that we develop other interests – and there is nothing inherently wrong in these, whether electronic games or films, or celebrity goings-on; the problem only emerges if we come to think of these as a replacement for the real world, and that there is no other reality that matters any more. Diversity of places (and their associated memories) is good, as it provokes imagination and desire and provides stability at the same time. It makes us think about how to solve new problems, how to understand things. After all, we all have genes passed on from a group of hominids that left the savannahs of Africa and dispersed across the world – discovering new environments, learning sufficiently rapidly to prevent consumption by larger predators and changing the world to suit us.

Evidence suggests that we have some innate connections to nature and also to diverse environments. When, then, do we lose heart and interest? When we no longer feel we can influence the future. When we have a repetitive and boring job, or when the commute to work is the same, day after day. We then yearn for something else, something new, an escape. Why do we go to different places for our holidays and in our leisure time? Why do we wish to visit the big city when we grow up in the country? Why do we wish to follow our relatives to another country? Of course, finance and opportunity play a role. That cities have streets paved with gold is an enduring component of many myths and stories. And when we do not move, then we do something else to keep up the interest and provoke imagination – we tell stories and create myths. We make the world more interesting by telling stories, which may carry important messages, but which most importantly seem to make our lives have more meaning. They are fuel for our minds. And without this, we are diminished, and our mental well-being suffers. We need mysteries and questions, as memories link the present to the past, compressing time into space. But a monoscape has no mysteries and no memories.

If we no longer have a big story that matters, we may no longer care. Despite great scientific consensus on the harm being caused to our planet, there is extraordinarily little macro-political or economic imperative that something fundamental might need to change. Why is this? Is it so easy to ignore the evidence or bodies of opinion on the effects of pollution or harm to the environment in the name of economic need or greed? We are going to need, at the very least, a better story. Increasing disconnections from nature mean more urbanisation and fewer rural communities, a more corporate world and less community spirit, more speed and less time, more simple solutions that do not recognise the world's complexity and diversity. As disconnections increase, we must in the end suffer a personal loss – in emotional well-being and in common identity. This will create a positive feedback, especially if we collectively do not realise why we face physical and mental ill-health. It is difficult enough to specify the effects of increased ultraviolet light on the skin because of diminished atmospheric ozone. But what about the effects of living by a forest compared with a concrete-dominated urban landscape? Or walking to work along a leafy lane versus a daily commute inside a half tonne of metal on rubber wheels? And so things will get worse, not better, unless we tell a different story and act differently, every one of us.

A phase of ecolution is now required, in which the value of cultural diversity is reaffirmed and the value of biological diversity is recognised and increased. But will this lead to the survival of the greenest – or simply once again the richest (or even the most environmentally destructive)? A preserved, green world has more opportunities for emotional well-being for the people in it – and different people like different environments, from the tundra to tropical rainforests, from the savannahs to the sands (and theatres, cafes and concert halls). If we lose these environments, then we lose the opportunity to express some of our genes, and thus these will decrease in frequency over time. And we will change. An environmentally impoverished world will be a post-human world. As the poet Gary Snyder says:

> *how could we **be** were it not for this planet that provided our very shape? The land gave us a stride, and the lake a dive [...] We should be thankful for that.*

Ecolution, then, suggests the need to recognise the tightly coupled nature of ecological and social systems and to develop new opportunities for creative self-organisation for enduring with this world. Our condition is linked to that of the planet. Now they are both in crisis, on a collision course, with the potential for destruction of biodiversity, cultures and life on this planet as we know it. In an imagined post-industrial world, human populations will fall, perhaps to as low as half of our current numbers. Many pressures will then have been lifted. But can we make it across this century, possibly the most critical of all human history?

Put simply, we collectively have the choice. Our genes are saying nothing. T S Eliot said that 'humankind cannot bear very much reality'. Our genes are at the mercy of the environment, as Matt Ridley points out. What kind of natural and social environments will we now create – ones that are harmful to us and our genes, or ones in which we can co-evolve and survive?

'The Earth only Endures' by Jules Pretty, chapter 15, 'Ecolution' – pages 197–211