Where does our behaviour come from?

PATRICK BATESON
The Provost's Lodge, King's College, Cambridge CB2 1ST, UK
(Fax, 44-1223-331195; Email, ppgb@cam.ac.uk)

1. Introduction

The fertilized egg from which each person develops is barely visible to the eye. The adult human body consists of millions upon million of cells doing different things. Nerve cells, skin cells and white blood cells, for example, all contain the same set of genes but are highly specialised for particular tasks. The cells are integrated within organs devoted to specific functions such as digesting food, pumping nutrients and oxygen to remote corners of the body, and integrating body movement in ways that serve the overall need of the whole individual to survive and reproduce. How does a human transform itself from a tiny single cell into a self-aware individual with the capacity for making astonishing computations and able to plan far into the future?

With increasing frequency the media report the discovery of a gene 'for' some distinct human characteristic, such as learning foreign languages, athletic prowess or male promiscuity. Yet it is obvious that experience, education and culture make a big difference to how people behave, whatever their genetic inheritance. Why is it that behavioural and psychological development is so often explained in terms of the exclusive importance of one set of factors, either genetic or environmental? Over simplified opinions may derive from a style of advocacy that is common in many scientific debates. If Dr Jones has overstated her case, then Professor Smith feels bound to redress the balance by over-stating the counter-argument. The confusions are amplified because of the way in which scientists analyse developmental processes. When somebody has conducted a clever experiment demonstrating an important long-term influence on behaviour, they have good reason to feel pleased. It is easy to forget about all those other influences that they had contrived to keep constant or which play no systematic role. Consequently, debates about behavioural and psychological development often degenerate into sweeping assertions about the overriding importance of genes (standing in for 'nature') or the crucial significance of the environment (which then becomes 'nurture'). Understanding behavioural development means understanding the biological and psychological processes that build a unique adult from a fertilized egg. It does not mean trying to explain human behaviour in terms of the conventional opposition between nature (genes) and nurture (environment).

The arguments mounted in this essay are by no means original to myself. I was supervised as a graduate student by Robert Hinde in the early 1960s and his opposition to the nature-nurture dichotomies (Hinde 1969) commonly deployed at that time had a strong influence on me. By his writings and ebullient character Danny Lehrman (1953, 1970) also had a lasting effect on me. Many contemporaries have been writing in a similar vein to myself and I have greatly benefited from our many interactions. I should particularly like to single out Susan Oyama (1985), Gilbert Gottlieb (1992) and Tim Johnston (1988). The rise of sociobiology (Wilson 1975) and more recently, evolutionary psychology (Tooby and Cosmides 1992) led to a temporary eclipse of developmental approaches to behaviour, but we now witness the re-integration of the different approaches to the study of behaviour. An important synthesis, sometimes described as developmental systems theory, and its intellectual origins are brought together by Oyama *et al* (2001) which is an invaluable modern reference.

2. Genes matter

Plant and animal breeders have known long enough that many of the characteristics that matter to them are inherited, in the sense that a new set of progeny will resemble individuals in the ancestral pedigree of that plant or animal more than they would resemble progeny from some other pedigree. Long before genes and DNA were discovered, breeders took this as a bountiful fact of life, even though they had no idea how inheritance worked.

For centuries, and in some cases millennia, domestic animals have been artificially selected by humans for breeding because they exhibit specific physical or behavioural features which are regarded as desirable. Dogs in particular, have for many centuries been bred for their behavioural characteristics. The sheepdog is especially sensitive to the commands of humans, waiting until the shepherd gives it a signal to start herding the sheep. Another breed, the pointer, behaves in a way that helps in sports shooting. When the pointer detects the smell of a game species such as a grouse, the dog stops in its tracks, stiffly orientated towards the bird. Valued behavioural characteristics such as these are clearly inherited, do not need to be taught (at least, not in their most basic form) and are quickly lost if breeds are crossed with others. Humans may also reveal through their children how particular characteristics are inherited. Two healthy parents from a part of the world where malaria is rife may have a child who develops severe anaemia. Both parents carry a gene that does have some effect on red blood cells, protecting them against the malarial parasite which enters red blood cells for part of its life-cycle (Veytsman 1997). However, a double dose of this recessive gene leads to the red blood cells collapsing from their normal biconcave disc shape into strange sickle-like shapes. The child who receives this genetic legacy develops sickle-cell anaemia.

Few behavioural characteristics are inherited in as simple a fashion as sickle-cell anaemia, and when they do the effects are usually damaging and pervasive. A well known case is the disabling disease phenylketonuria (PKU). If a child inherits two copies of a particular recessive gene from both its parents, it cannot produce a crucial enzyme required to break down phenylalanine, an amino acid which is a normal component of the average diet. The resulting accumulation of phenylalanine in the body poisons the child's developing brain and causes severe mental retardation – unless the condition is diagnosed and the child is given a special diet.

Evidence for genetic influences on human behaviour is usually indirect. It is bound to be so because naturally-occurring breeding experiments are rare, and deliberate breeding experiments in the interests of genetic research would obviously be intolerable in most societies. What is more, many genes are involved in the great majority of family likenesses, whether physical or behavioural. However, some light is cast on the links between genes and behaviour by the study of twins.

Research into the inheritance of human behaviour has been greatly helped by comparing genetically identical twins with non-identical twins. Identical (or monozygotic) twins are genetically identical because they are derived from the splitting of a single fertilized egg. They are naturally-occurring clones. Non-identical (or dizygotic) twins, in contrast, develop from two fertilized eggs. Consequently, they are genetically as dissimilar as two siblings born at different times. In the western world, about 1 in 83 births are twins, of which a third are identical twins.

If identical twins are no more alike than non-identical twins in a given behavioural characteristic, then this suggests that the genetic influence on that characteristic is weak. Conversely, when identical twins are substantially more alike than non-identical twins (or siblings) then the mechanism of inheritance is likely to be through the nuclear genes.

Another way of exploring how genes influence behaviour is to compare twins who have been reared apart (because one or both of them has been adopted soon after birth) with twins who have been reared together. The thought behind this approach is that separation in early infancy removes the influence of the shared environment, leaving only the inherited factors. The thought is not wholly correct, however, because even twins who are separated immediately after birth will have shared a common environment for the first crucial nine months after conception, while they are in their mother's womb (Devlin *et al* 1997). This obvious truth can add to the difficulties of sorting out the sources of individual distinctiveness. Moreover, being separated at birth and raised in environments that are assumed to be different does not preclude the possibility that their environments may in fact have many important features in common.

Nevertheless, the appearance, behaviour and personality of identical twins who have been reared apart are often startlingly similar. In one documented case, for example, a pair of twins had been separated early in life, with one growing up in California and the other in Germany. Yet when they met for the first time in 35 years, they both arrived wearing virtually identical clothes and with similar clipped moustaches; both had a habit of wrapping elastic bands around their wrists; and both had the idiosyncratic habit of flushing lavatories before as well as after using them (Wright 1997).

Accounts such as these are sometimes greeted with scepticism, because it is suspected that only the startling matches have been reported while the discrepant twins have been ignored in the interests of a good story. Nevertheless, some well-conducted statistical surveys have revealed that on a range of measures of personality, identical twins who have been reared apart are more like each other than non-identical twins who have also been reared apart (Bouchard *et al* 1990). When making such comparisons it does not matter whether, as has often been argued, the measures of behavioural characteristics are crude and relatively insensitive. While differences are less likely to be found with insensitive behavioural measures, differences are found. The inescapable conclusion is that some observable aspects of individuals' behaviour are influenced by inherited factors.

Further evidence for genetic influences comes from observing patterns of behavioural development. Many aspects of behaviour and intellectual functioning do not develop at a steady rate. Obvious mental 'growth spurts' are found in children's capacities for complex thought and reasoning, and individual children differ in the chronological ages at which these developmental spurts occur (Wilson 1983). As with many other behavioural characteristics, identical twins are more alike in the timing of such developmental spurts than non-identical twins. This implies that individual differences in the patterns of behavioural development themselves are influenced by inherited factors.

3. Experience matters

Even the most cursory glance at humanity reveals the enormous importance of each person's experience, upbringing and culture. Look at the astonishing variation among humans in language, dietary habits, marriage customs, child care practices, clothing, religion, architecture, art and much else besides. Nobody could seriously doubt the remarkable human capacity for learning from personal experience and learning from others.

Early intervention can benefit the disadvantaged child, but in ways that had not been fully anticipated. In the 1960s, great efforts were made in the USA to help people living in difficult and impoverished conditions. A large government programme known as Headstart was designed to boost children's intelligence by giving them educational experience before starting school. But the programme did not seem to have the substantial and much hoped-for effects on intelligence, as measured by IQ (Mackintosh 1998). Children who had received the Headstart experience displayed an initial, modest boost in their IQ scores, but these differences soon diminished after a few years. The fashionable response was to disparage such well-meaning efforts to help the disadvantaged young.

Later research, however, has revealed that some of the other effects of the Headstart experience were long-lasting and of greater social significance – than boosting IQ scores. Several long-term follow-up studies of children who had received pre-school training under Headstart found that they were distinctive in a variety of ways, perhaps the most important being that these individuals were much more community-minded and less likely to enter a life of crime (Schweinhart *et al* 1993). Headstart produced overall lasting benefits for the recipients and society and but not by merely raising raw IQ scores. Evidence for the long-term benefits of early educational intervention has continued to accumulate (Yoshikawa 1995). Studies like these raise many questions about the ways in which early experiences exert their effects, but they do at least show how important such experiences can be.

Even relatively subtle differences in the way children are treated at an early age can have lasting effects on the way they behave years later. One study compared the long-term effects of three different types of pre-school teaching (Schweinhart and Weikart 1997). In the first type, three- and four-year-olds were given direct instruction with the teacher initiating the children's activities in a strict order. The second type of teaching was a traditional nursery school in which the teachers responded to activities initiated by the children. In the third, known as High/Scope, the teachers involved the children in planning their own activities, but arranged the classroom and the daily routine so that the children could do things that were appropriate to their stage of development.

Striking differences were found between the children as they grew up. When followed up at the age of 23, the individuals who had been in the direct instruction group were worse off in a variety of ways than those in the other two groups. In particular, they were more likely to have been arrested on a criminal charge and more likely to have received special help for emotional impairment. In comparison, people who had received the relaxed type of pre-schooling were more likely to be living with spouses and much more likely to have developed a community spirit.

4. Understanding the inter-play

The importance of both genes and environment to the development of all animals, including humans is obvious. This is true even for apparently simple physical characteristics, let alone complex psychological variables. Take myopia (or short-sightedness) for example. Myopia runs in families, suggesting that it is inherited. But it is also affected by the individual's experience. Both a parental history of myopia and, to a lesser extent, the experience of spending prolonged periods studying objects close-up will predispose a child to become short-sighted (Zadnik 1997).

A more interesting case is musical ability, about which strong and contradictory views are held. Popular beliefs about the origin of special talents are generally that they are inherited. Dissociation between general intellectual capability and musical ability is strongly suggested by the phenomenon of the musical idiot-savant – an individual with low intelligence but a single, outstanding talent for music (O'Connor 1989). Such people are usually male and often autistic. Their unusual gift – whether it be for music, drawing or mental arithmetic – becomes apparent at an early age and is seldom improved by practice. One typical individual could recall and perform pieces of music with outstanding ability and possessed almost perfect pitch; he had poor verbal reasoning, but his low intellectual ability was to some degree offset by high levels of concentration and memory. However, children who are good at music also tend to be good at reading and have a good sense of spatial relations, even after taking account of variables such as age and IQ (Barwick *et al* 1989).

The main factors fostering the development of musical ability form a predictable cast: a family background of music; practice (the more the better); practical and emotional support from parents and other adults; and a good relationship with the first music teachers (Sloboda 1993). Practice is especially important, and attainment is strongly correlated effort. A rewarding encounter with an inspirational teacher may lock the child into years of effort, while conversely an unpleasant early experience may cause the child to reject music, perhaps forever. Here, as elsewhere, chance plays a role in shaping the individual's development.

Research on identical and non-identical twins has shown that the shared family environment has a substantial influence on the development of musical ability, whereas inherited factors exert only a modest effect. Genetically identical twins are only slightly more alike in their musical ability than non-identical twins or siblings (Coon and Carey 1989). A study of more than 600 trainee and professional musicians analysed the origins of perfect (or absolute) pitch – that is, the ability to hear a tone and immediately identify the musical note without reference to any external comparison (Baharloo *et al* 1998). Heritable factors appeared to play a role, as musicians with perfect pitch were four times more likely than other musicians to report having a relative with perfect pitch. But the same study also found that virtually all the musicians with perfect pitch had started learning music by the age of six. Of those who had started musical training before the age of four, 40% had developed perfect pitch, whereas only 3% of those had started training after the age of nine possessed the ability.

Like many other complex skills, musical ability develops over a prolonged period; and the developmental process does not suddenly stop at the end of childhood. Expert pianists manage to maintain their high levels of musical skill into old age despite the general decline in other faculties (Krampe and Ericsson 1996). They achieve this through copious practice throughout their adult life; the greater the amount of practice, the smaller the age-related decline in musical skill. Practice not only makes perfect, it maintains perfect.

Is it possible to calculate the relative contributions of genes and environment to the development of behaviour patterns or psychological characteristics such as musical ability? Given the passion with which clever people have argued over the years that either the genes or the environment are of crucial importance in development, it is not altogether surprising that the outcome of the nature-nurture dispute has tended to look like an insipid compromise between the two extreme positions. Instead of asking whether behaviour is caused by genes or caused by the environment, the question instead became: 'How much is due to each?' In a more refined form, the question is posed thus: 'How much of the variation between individuals in a given character is due to differences in their genes, and how much is due to differences in their environments?'

The nature-nurture controversy appeared at one time to have been resolved by a neat solution to this question about where behaviour comes from. The suggested solution was provided by a measure called heritability. The meaning of heritability is best illustrated with an uncontroversial characteristic such as height, which is clearly influenced by both the individual's family background (genetic influences) and nutrition (environmental influences). The variation between individuals in height that is attributable to variation in their genes may be expressed as a proportion of the total variation within the population sampled. This index is known as the heritability ratio. The higher the figure, which can vary between 0 and 1·0, the greater is the contribution of genetic variation to individual variation in that characteristic. So, if people differed in height solely because they differed in their genes, the heritability of height would be 1·0. If on the other hand, variation in height arose entirely from individual differences in environmental factors such as nutrition then the heritability would be 0. More than 30 twin studies, involving a total of more than 10,000 pairs of twins have collectively produced an estimated heritability for IQ of about 0·5 (ranging between 0·3 and 0·7) (Plomin 1990). Twin and adoption studies of personality measures, such as sociability/shyness, emotional and activity level, have typically produced heritabilities in the range 0·2 to 0·5 (Plomin *et al* 1997).

Calculating a single number to describe the relative contribution of genes and environment has obvious attractions. Estimates of heritability are of undoubted value to animal breeders, for example. Given a standard set of environmental conditions, the genetic strain to which a pig belongs will predict its adult body size better than other variables such as the number of piglets in a sow's litter. If the animal in question is a cow and the breeder is interested in maximising its milk yield, then knowing that milk yield is highly heritable in a particular strain of cow under standard rearing conditions is important.

But behind the deceptively plausible ratios lurk some fundamental problems. For starters, the heritability of any given characteristic is not a fixed and absolute quantity – though many scientists have been tempted to believe otherwise. Its value depends on a number of variable factors, such as the particular population of individuals that has been sampled. For instance, if heights are measured only among people from affluent backgrounds, then the total variation in height will be much smaller than if the sample also included people who are short due to undernourishment. The heritability of height will consequently be larger in a population of exclusively well-nourished people than it would be among people drawn from a wider range of environments. Conversely, if the heritability of height is based on a population with relatively similar genes – say, native Icelanders – then the figure will be lower than if the population is genetically more heterogeneous; for example, if it includes both Icelanders and African pygmies. Thus, attempts to measure the relative contributions of genes and environment to a particular characteristic are highly dependent on who is measured and in what conditions.

Another problem with heritability is that it says nothing about the ways in which genes and environment contribute to the biological and psychological cooking processes of development. This point becomes obvious when considering the heritability of a characteristic such as ‘walking on two legs’. Humans walk with less than two legs only as a result of environmental influences such as war wounds, car accidents, disease or exposure to teratogenic toxins before birth. In other words, all the variation within the human population results from environmental influences, and consequently the heritability of ‘walking on two legs’ is zero. And yet walking on two legs is clearly a fundamental property of being human, and is one of the more obvious biological differences between humans and other great apes such as chimpanzees or gorillas. It obviously depends heavily on genes, despite having a heritability of zero. A low heritability clearly does not mean that development is unaffected by genes.

If a population of individuals is sampled and the results show that one behaviour pattern has a higher heritability than another, this merely indicates that the two behaviour patterns have developed in different ways. It does not mean that genes play a more important role in the development of behaviour with the higher heritability. Important environmental influences might have been relatively constant at the stage in development when the more heritable behaviour pattern would have been most strongly affected by experience.

Yet another serious weakness with heritability estimates is that they rest on the incorrect assumption that genetic and environmental influences are independent of one another and do not interact. The calculation of heritability assumes that the genetic and environmental contributions can simply be added together to obtain the total variation. In many cases this assumption is clearly wrong. For example, in a study involving rats, the animals’ genetic background and their rearing conditions were both varied; rats from two genetically inbred strains were each reared in one of three environments, differing in their richness and complexity (Cooper and Zubek 1958). The rats’ ability to find their way through a maze was measured later in their lives. Rats from both genetic strains performed equally badly in the maze if they had been reared in a poor environment (a bare cage) and equally well if they had been reared in a rich environment filled with toys and objects. Taken in isolation, these results implied that the environmental factor (rearing conditions) was the only one that mattered. But it was not that simple. In the third type of environment, where the rearing conditions were intermediate in complexity, rats from the two strains differed markedly in their ability to navigate the maze. These genetic differences only manifested themselves behaviourally in this sort of environment. Varying both the genetic background and the environment revealed an interplay between the two influences.

An overall estimate of heritability has no meaning in a case such as this, because the effects of the genes and the environment do not simply add together to produce the combined result. The effects of a particular set of genes depend critically on the environment in which they are expressed, while the effects of a particular environment depends on the individual’s genes. Even in animal breeding programmes which use heritability estimates to practical advantages, care is still needed. If breeders wish to export a particular genetic strain of cows which yield a lot of milk, they would be wise to check if the strain would continue to give high milk yields under the different environmental conditions of another country. There are many cases where a strain that performs well on a particular measure in one environment does poorly in another, while a different strain performs better in the second environment than in the first.

Any scientific investigation of the origins of human behavioural differences eventually arrives at a conclusion that most non-scientists would probably have reached after only a few seconds’ thought. Genes and the environment both matter. The more subtle question about how much each of them matters defies an easy answer. There is no simple formula to solve this conundrum, and the problem needs to be tackled differently.

5. Developmental processes

The idea that genes might be likened to the blueprint of a building must be scrapped immediately – at least as far as behaviour is concerned. The idea is hopelessly misleading because the correspondences between plan and product are not to be found. In a blueprint, the mapping works both ways. Starting from a finished house, the room can be found on the blueprint, just as the room's position is determined by the blueprint. This straightforward mapping is not true for genes and behaviour, in either direction. The language of a gene 'for' a particular behaviour pattern, so often used by scientists is exceedingly muddling to the non-scientist (and if the truth is to be told, to many scientists as well). What the scientists mean (or should mean) is that a genetic difference between two groups is associated with a difference in behaviour. They know perfectly well that other things are important and that, even in constant environmental conditions, the developmental outcome depends on the whole gene 'team'. Particular combinations of genes have particular effects, in much the same way as a particular collection of ingredients may be used in cooking a particular dish; a gene that fits into one combination may not fit into another. Unfortunately, the language of genes 'for' characters has a way of seducing the scientists themselves into believing their own sound-bites.

The adult human brain has around one hundred thousand million (10^{11}) neurons, each with hundreds or thousands of connections to other neurons. A diagram of even a tiny part of the brain's connections would look like an enormously complex version of a map of the London underground railway system. The brain is organized into sub-systems, many of which are dedicated to different functions which are run separately but are integrated with each other. Since the behaviour of the whole animal is dependent on the whole brain, it will be obvious why it is not sensible to ascribe a single aspect of behaviour to a single neuron, let alone a single gene. The pathways running from genes to neurons and thence to behaviour are long, full of detours, with many other paths joining it and many leading away from them.

Nothing happens in isolation. The products of genes and the activities of neurons are all embedded in elaborate networks. Each behaviour pattern or psychological characteristic is affected by many different genes, each of which contributes to the variation between individuals. In an analogous way, many different design features of a motor car contribute to a particular characteristic such as its maximum speed. Conversely, each gene influences many different behaviour patterns. To use the car analogy again, a particular component such as the system for delivering fuel to the cylinders may affect many different aspects of the car's performance, such as its top speed, acceleration and fuel consumption. The effect of any one gene also depends on the actions of many other genes.

Modern technology allows particular genes to be knocked out of action (Coen 1999). Numerous experiments on mice have found that an effect on the whole animal of changing one gene is only observed in particular genetic strains – that is, when a particular combination of other genes is also present. Sometimes, when one or other of two genes is knocked out, no change is observed in either case, but a big change is found if both genes are inactivated. Some genes are only expressed in special environmental conditions. For example, a variant of one particular gene in the fruit fly *Drosophila* causes paralysis – but only when the environmental temperature exceeds 29°C (Wu *et al* 1978). In development, as in cooking a soufflé, a small difference in temperature can make a big difference to the outcome.

It is clear then, that because of the immensely complex system in which they are embedded, no simple correspondence is found between individual genes and particular behaviour patterns or psychological characteristics. Genes store information coding for the amino acid sequences of proteins; that is all. They do not code for parts of the nervous system and they certainly do not code for particular behavioural patterns. Any one aspect of behaviour is influenced by many genes, each of which may have a big or a small effect. Conversely, any one of the many genes can have a major disruptive effect on a particular aspect of behaviour. A disconnected wire can cause a car to break down, but this does not mean that the wire by itself is responsible for making the car move.

An illustration of the long and indirect path from genes to behaviour is provided by the Kallmann syndrome, a genetic condition that afflicts only men (Pfaff 1997). The main behavioural consequence of this genetic defect is a lack of sexual interest in members of the opposite sex. Kallmann syndrome is caused by damage at a specific genetic locus. Cells that are specialized to produce a chemical messenger called gonadotropin-releasing hormone (GnRH) are formed initially in the nose region of the foetus. Normally the hormone-producing cells would migrate into the brain. As a result of the genetic defect, however, their surface properties are changed and the cells remain dammed at the nose. The activated GnRH cells, not being in the right place, do not deliver their hormone to the pituitary gland at the base of the brain. Without this hormonal stimulation, the pituitary gland does not produce the normal levels of two other chemical messengers, luteinizing hormone and follicle stimulating hormone. Without these hormones, the testes do not produce normal levels of the male hormone testosterone. Without normal levels of testosterone, the man shows little sign of normal adult male sexual behaviour. As a result, men suffering from Kallmann syndrome have a reduced libido and are not attracted to either sex. Even in this relatively straightforward example, the pathway from gene to behaviour is long, complicated and indirect. Each step along the causal pathway requires the products of many genes and has ramifying effects, some of which may be apparent and some not.

Many birds specialize in eating particular types of seeds, but the size of the bill differs greatly between species. Seeds also differ greatly in size, from some that are only a millimetre across to a hazel nut which is more than ten times the diameter. When they are young, birds experiment with different sizes of seed until they find ones that are particularly well suited to their bills (Kear 1962). The young bird learns to pick the food source to which its body is best suited. Similarly, as children grow up, they are given copious advice about choosing careers that best suit their aptitudes. They also actively choose circumstances they find congenial, or ones with which they are best able to cope. This means that people who differ consistently in ways that relate to differences in their genes may also predictably pick certain physical and social environments in which to live. The possibility that they might do this has been given the splendid name of "niche-picking" (Scarr and McCartney 1983). It means that individuals with different characteristics, some of which reflect the differences in their genes, end up by their own actions experiencing the world in quite different ways.

A long debate has revolved around whether boys and girls differ in their behaviour because they are genetically different from each other or because they are treated differently from a young age. A consensus has formed that early in their development, boys on an average are more assertive and individualistic, while girls tend to be more expressive and interested in personal relationships (Hinde 1997). Comparable sex differences in behaviour are found in monkeys and apes. The initial sex differences in humans often sharply reduce as children develop – at least under some conditions. Under other conditions, however, the differences are amplified by the normal practices of the society in which they grow up and by their own habit of forming single sex groups in which to play. The boys exclude the girls from their gangs and likewise the girls tease or ignore boys who seek to enter their play. This may also be an example of niche-picking, where the niche differs greatly from one culture to another.

One surprising conclusion to emerge from studies of identical twins is that twins reared apart are sometimes more like each other than those reared together (Shields 1962). To put it another way, rearing two genetically identical individuals in the same environment can make them less similar rather than more similar because one of the twins is dominant over the other, such as entering the room first and speaking for both of them. This fact pleases neither the extreme environmental determinist nor the extreme genetic determinist. The environmental determinist supposes that twins reared apart must have different experiences and should therefore be more dissimilar in their behaviour than twins who grew up together in the same environment. The genetic determinist does not expect to find any behavioural differences between genetically identical twins who have been reared together. Their arguement would be that if they have had the same genes and the same environment, then how can they be different?

Siblings are less like each other than would be expected just by chance (Dunn and Plomin 1990). The child picks a niche for itself, not on the basis of its own characteristics but on what its siblings have done. Children seek out their own space. When Mary did well at art, her younger sister Susan would not have anything to do with drawing or painting, even though she would probably have been good at both. When Henry developed a flair for history and languages, George inclined towards maths and science. Most parents with more than one child can tell such stories. Such interplay between siblings probably accounts for some of the influences of birth order (ref.). Individual differences emerge because children are active agents in their own development. Other things are also at work, of course. Parents treat their successive children differently – sometimes deliberately, sometimes unwittingly. They often have a more taut relationship with their first child than with their later-born children, being more anxious and controlling (Rutter and Rutter 1993). They are usually more relaxed, positive and confident with their subsequent children and their preoccupation with every detail of their children's behaviour and appearance lessens. Many parents possess more family photographs of their first child than they do of their later children.

Learning is the most obvious way in which individuals interact with, and are changed by their environment. Learning is entwined in the processes of human behavioural development, adapting individuals' behaviour to local conditions, enabling them to copy the behaviour of more experienced people, and fine-tuning preferences and actions that were inherited from previous generations. The multiple roles of learning in moulding lives almost certainly involve different ways of extracting knowledge about regularities in the environment. Initially at least some of these underlying rules must themselves develop without learning, since the process must start somehow – the biological equivalent of computer bootstrapping. Learning the rules for learning itself requires developmental regularity. The world is full of confusing information. Each individual must know what to store and what to reject from a given experience. In a well-designed life even the initial rules for learning must be adapted to the function they serve.

The best known type of learning process was made famous by Pavlov a century ago. Pavlovian or classical conditioning, as it is called, allows the individual to predict what will be of real significance in the confusing world of sights, sounds and smells. Pavlov's famous experiment was to teach a dog to expect food by repeatedly alerting it with a buzzer before the food was presented. Pavlov measured how much saliva the dog produced. As the dog was conditioned by the predictable association between the buzzer and the food, it came to produce saliva in response to the sound of the buzzer alone. As any dog owner knows, a hungry dog will do many other things once it detects cues that predict the arrival of food; it will go to the food bowl, whine, wag its tail, jump up and show all the familiar signs of expectation.

In Pavlovian conditioning, the sequence in which the events occur is crucial. If the buzzer is sounded after the presentation of food to a dog that has not yet been conditioned, it will not salivate or show any other expectant signs when the buzzer is subsequently sounded. The link in time between the action and the outcome is crucial. The rules for discovering causal relations between things make sense in terms of their utility because they map closely onto how the world works.

Another form of learning leads to the recognition of faces and places. The ability to distinguish between the vast array of objects, other people and scenes experienced in a life-time is of inestimable value and happens simply as a result of exposure. The memory capacity is extraordinary. In one experiment people were shown up to 10,000 different slides projected onto a screen in quick succession. Days later they were able to recognize thousands of those images which they had previously seen. Some of the pictures, such as a dog smoking a pipe or a crashed airplane, were particularly vivid. In these cases the recall was even better and the subjects seemed to have a virtually limitless capacity to store them (Standing 1973).

Objects in the real world are rarely flat and their appearance depends on how they are viewed. A friend or relative is easily recognized from the front or the back, whether they are in the distance or close up. But they may not be so readily recognized if the photograph is taken from an odd angle such as from their feet. The recognizable features of a familiar person are fused together by the brain into a single category when these different views are seen in quick succession. Doubtless many other learning rules are also important in this case, such as lumping together different views seen in the same context (Bateson 2000). The point, though, is that time plays a different role in such perceptual learning than is usually the case in Pavlovian conditioning. The order in which different events are experienced is important when one event causes the other, but unimportant when the experiences are different views of the same object.

It seems likely that the initial rules for learning are themselves unlearned, universal and the products of Darwinian evolution. Does this mean that all human behaviour is predictable? The answer is emphatically 'No'. To understand why, consider a rule-governed game like chess. It is impossible to predict the course of a particular chess game from a knowledge of the game's rule. Chess players are constrained by the rules and the positions of the pieces in the game, but they are also instrumental in generating the positions to which they must subsequently respond. The range of possible games is enormous. Indeed, it is often unclear who is going to win until almost the end of the game. In a famous encounter between Robert Byrne and Bobby Fischer in 1963, Fischer seemed to have lost the game by the 21st move. He had just moved his queen and two Grandmasters who were providing a commentary for spectators declared that Byrne would win. In fact, Byrne knew better and eventually resigned without making another move because he realized he would be mated within four moves. Underlying rules of clear adaptive significance can generate surface behaviour of enormous complexity and inferring those underlying rules from watching many instances is difficult.

Nevertheless, it is likely that order underlies even those learning processes that make people different from each other. Knowing something of the underlying regularities in development does bring an understanding of what happens to the child as it grows up. The ways in which learning is structured, for instance, affect how the child makes use of environmental contingencies and how the child classifies perceptual experience. Yet predicting precisely how an individual child will develop in the future from knowledge of the developmental rules for learning is no easier than predicting the course of a chess game. The rules influence the course of a life, but they do not determine it. Like chess players, children are active agents. They influence their environment and are in turn affected by what they have done. Further, children's responses to new conditions will, like chess-players' responses, be refined or embellished as they gather experience. Sometimes normal development of a particular ability requires input from the environment at a particular time; what happens next depends on the character of that input. The upshot is that, despite their underlying regularities, developmental processes seldom proceed in straight lines. Big changes in the environment may have no effect whatsoever, whereas some small changes have big effects. The only way to unravel this is to understand developmental processes.

6. Conclusion

Looking for single causes, whether genetic or environmental, may yield answers of a kind, but little sense of what happens as each individual grows up. The language of nature versus nurture, or genes versus environment, gives only a feeble insight into the processes that I have called developmental cooking. The best that can be said of the nature/nurture split is that it provides a framework for uncovering a few of the genetic and environmental ingredients that generate differences between people. At worst, it satisfies a demand for simplicity in ways that are fundamentally misleading.

The search for simple environmental origins, which had wide appeal in the mid-twentieth century, has been partly superseded by an equally skewed belief in the over-riding importance of genes. If pressed, scientists may concede that their talk of genes ‘for’ shyness, maternal behaviour, promiscuity, verbal ability, criminality, or whatever, is merely a shorthand. They may nonetheless try to legitimize the language of genes ‘for’ behaviour, by pointing to seemingly straightforward examples like the genes for eye colour. Nonetheless, the notion of genes ‘for’ behaviour undoubtedly corrupts understanding.

A single developmental ingredient, such as a gene or a particular form of experience, might produce an effect on behaviour, but this certainly does not mean that it is the only thing that matters. Even in the case of eye colour, the notion that the relevant gene is the cause is misconceived, because all the other genetic and environmental ingredients that are just as necessary for the development of eye colour remain the same for all individuals. A more honest translation of the ‘gene for’ terminology would be something like: ‘We have found a particular behavioural difference between individuals which is associated with a particular genetic difference, all other things being equal.’ The media and the public might start to get the message if plain language like this were used routinely.

The commonly used image of a genetic blueprint for behaviour also fails because it is too static, too suggestive that adult organisms are merely expanded versions of the fertilized egg. In reality, developing organisms are dynamic systems that play an active role in their own development. Even when a particular gene or a particular experience is known to have a powerful effect on the development of behaviour, biology has an uncanny way of finding alternate routes. If the normal developmental pathway to a particular form of adult behaviour is impassable, another way may often be found. The individual may be able, through its behaviour, to match its environment to suit its own characteristics. At the same time, playful activity increases the range of available choices and, at its most creative, enables the individual to control the environment in ways that would otherwise not be possible.

Development is not like a fixed musical score, which specifies exactly how the performance starts, proceeds and ends. It is more like a form of jazz in which musicians improvise and elaborate their musical ideas, building on what the others have just done. As new themes emerge, the performance acquires a life of its own, and may end up in a place none could have anticipated at the outset. Yet it emerges from within a fixed set of rules and the constraints imposed by the musical instruments.

It no longer seems obscure to talk about systems and processes. The linear thinking of a previous generation, with every event having a single cause, is slowly being replaced by an understanding of coordinated process.

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