The brain and learning

Cells in the brain

A human brain consists of about 100 billion (10^{11}) nerve cells, or neurons, supported by other cells (glial cells), bathed in a fluid (the cerebrospinal fluid) and supplied with blood. The glial cells have several different functions in the brain, but it is the **neurons** that are thought to be responsible for our *cognitive processes* (thinking – imagining, remembering, etc.).

Electrical pulses move along nerve cells, and may sometimes trigger a pulse in an adjacent nerve cell. The junction between nerve cells is called a synapse, and the gap between 'connected' cells is very small (about 0.000 005 mm). When an electrical signal reaches the end of a nerve cell, the cell releases chemicals, 'neurotransmitters', that diffuse across the gap, and sometimes trigger the start of pulse in the next neuron. A stronger electrical signal will tend to lead to the release of more chemicals, and is more likely to affect the next neuron. Sometimes, however, the signal from one neuron inhibits, rather than stimulates, the neuron it synapses with. Not all synapses are equally effective – the connections are 'tuned' differently, so some links are more likely to be triggered than others. A very important property of the brain is that it changes – cells grow (and die), and new connections are made, and existing connections strengthened, weakened or broken. This plasticity of the system allows us to learn.

Nerve cells are not connected in simple linear fashion. Indeed, some neurons can have up to 100 000 inputs (although 10 000 is more typical – still a very large number)! This means that whether a neuron 'fires' can depend upon the overall effect of a large number of other neurons that are communicating with it. The brain is a very complex network of connected neurons: a network constantly being adjusted by our experiences.

Perception

Provided it is well-maintained (e.g. a good supply of blood) the mature human brain seems to be able to keep active without any immediate input – think of what happens during dreaming. However, the brain operates on information provided by the senses.

The brain receives a constant flow of information from nerves connected to sense organs throughout the body. The obvious inputs are from the eyes, ears, and from the nose and taste buds. However, information is constantly arriving from various receptor cells indicating pressure, temperature, etc, especially from the skin. Most of the time we are unaware of much of this input. In particular the nervous system is designed so that it is often much more sensitive to changes than to constant situations. (So if you sit on a hard or cold surface you may soon cease to notice the discomfort if your attention is elsewhere).

It is easy to assume we see and hear what is out there in our environment because that is what is out there. This is a gross over-simplification. The brain has to learn to interpret the signals from our eyes and ears – to make sense of the input. The baby cannot recognise objects even when its eyes are working perfectly – the connections have to be made between the retina and the area of the brain that will process the signals arriving from the optic nerve. Even then, it takes time for the moving smudges of colour and shape to start to be interpreted as people, food, toys etc. Older children have learnt to recognise many patterns instantly (and 'see' them as people, objects etc., rather than as shapes and colours) but even an adult occasionally has trouble identifying a pattern.

The same is true with sounds. For example, our brains become 'tuned' to the types of sounds commonly used in the language we hear everyday. This makes it very difficult to learn a language that divides the sound spectrum in different ways – for example native speakers from the Far East often mispronounce English words in characteristic ways because they cannot hear common differences in English (and it works the other way round of course). This is not because their ears are incapable of detecting the different sounds, but because the part of the brain that receives the signal form ears has developed a set way of processing the sounds.

Research has shown that to help us hear what people say, children's brains learn to categorise speech sounds in ways that match the language we hear when we are quite young. This makes us efficient at working out what people say in our language – but makes us deaf to other possible speech sounds that are used in other languages.

As an analogy, imagine a machine that is designed to classify coins. It could have slots that take coins of all shapes and sizes, and detects all the information marked on the coins. The machine might then have a mechanism that sorts the coins by the date they were minted. Another machine could accept the same coins, and collect the same information about the coins, but have a mechanism that sorts them by value. Different parts of the same initial information would be selected (or discarded) and acted upon differently by the two machines, even thought they may seem identical from the outside. To be a better analogy, these machines would have to build their own mechanism to sort the coins, depending upon whether the other machines in their community took notice of the date or value on the coins!

In a similar way, as we learn to interpret common visual patterns automatically, we can sometimes misinterpret visual information because of the patterns our brains have learnt to expect to see.

Subconscious thought?

So, much of the brain's activity relating to the monitoring and maintenance of the body goes on without us being aware of it. Indeed, this is also true of much of our 'mental lives': we are not always aware of our thinking processes!

Sigmund Freud made his name by developing the branch of psychology known as psychoanalysis. It is assumed by psychoanalysts that people are sometimes not aware of the true reason for their own behaviour – that sometimes we have motives that we are not conscious of. Sometimes these subconscious thoughts may be pathological – they may makes us unhappy, aggressive, defensive, worried etc. The analyst uses techniques such as word-association to help the client explore their unconscious feelings. Not everyone is totally convinced by the details of Freud's theories, but the basic principle of subconscious motives and fears seems sound, and has given us the popular notion of a 'Freudian slip' (where we say the 'wrong' word, but supposedly use a word that is associated with our deep feelings, so revealing our 'true' feelings or interests).

Intuition and science

Science is often presented as a rational and logical process, but - like many human activities - the reality can often be more messy. Good science does require careful logical thought. However, some quite important scientific discoveries have largely down to luck, and sometimes serendipity (lucky accidents) – such as the broken thermometer that revealed an unexpected chemical property of mercury!

The most famous example is probably the accidental discovery of the antibiotic effects of penicillin. The growth of the penicillin mould on Fleming's culture plates was considered to be an inconvenient nuisance, and the discovery was initially consigned to the laboratory's washing-up pile - until its significance was appreciated.

Many scientists accept that the process of scientific discovery often has an aspect which is due to a type of thinking that occurs below the level of consciousness. Kekulé [Kek-U-lay] claimed to have discovered the chemical structure of benzene whilst dozing off after a tiring day. He could not match the properties of benzene and the experimental data on how much carbon and hydrogen was present in the substance benzene (C6H6), with any structure he could think of. Then he fell asleep and dreamt about a ring of snakes, and when we awoke he realised that a structure with the carbon atom arranged in a ring would fit the data. We now know that there are a lot of compounds with rings – many sugars for example – but this seemed an unusual idea at the time.

Sleeping may not seem the obvious approach to solving scientific problems (although it may seem an inviting one sometimes) but there are many other examples of scientists claiming their discoveries came to them when relaxing – when bathing (Archimedes' 'Eureka' moment), listening to music, or out walking for example.

There are two aspects of this phenomenon that should be of interest to science students – how we can sometimes solve problems without being aware that we are doing it; and how we can match the expectation that science is a rational process with the discoveries made whilst we are not aware we are thinking about a topic.

Discovery and Justification

In science it does not matter how one arrives at an idea – as long as it is possible to support it with argued evidence when presenting it to the scientific community. So it is not important to scientists that Kekulé literally dreamt-up his idea about benzene having a ring structure – it fitted the data available then, and it has helped explain many, many more experimental results since. The structure is accepted, but not because of the dream, nor in spite of it, but regardless of it. The structure is accepted because it 'works' in a large number of scientific explanations, fitting with other accepted theory to make sense of experimental findings.

This is because there is a distinction made between the discovery of a new scientific principle and its justification. Scientific ideas are accepted if they can be shown to fit with and explain the results of experiments, and they are consistent with other accepted scientific ideas (that themselves fit other experimental data).

When scientific research is written-up for the research journals, the scientist has to give details about how the work was undertaken, and how the results were collected and analysed, as well as explaining why the conclusions drawn follow on from the results. Other scientists expect these reports to be logical, with a full argument explaining all the steps in the thinking. Immunologist Peter Medawar suggested that because of this need to justify ideas, scientific research papers often gave the impression that science itself is a tidy process, with the results following from a carefully planned series of steps. Science could only be like this if it was always possible to know in advance the results of experiments – which would make science much less fun and interesting, and perhaps largely pointless. In reality, there are often many false steps, and the odd lucky break, on the way to any useful scientific results.

Medawar asked if the scientific research paper was ‘a fraud’, presenting a picture of science that did not reflect reality. However, scientific research papers are meant to argue the logical case for the importance of findings, rather than describing the often messy (and often exciting) process by which the results were obtained.

The role of imagination

In many scientific discoveries there is a step which requires the use of creativity, or imagination, rather pure logic. So Newton was not the first person to spot an apple falling from a tree – but he made the creative leap of imagining that the moon was ‘falling’ towards the earth in an analogous way, and that the force that caused the apple to fall might also keep the moon orbiting. It is impossible to be sure how and why Newton’s brain made this association, but this moment of insight led to his theory of universal gravitation. Had Newton been content to have entertained the idea, but not followed it up, it would not have been a key moment in science. It became important because Newton was prepared to use this as the starting point for developing a new mathematical model. When Newton published his ideas, they were judged on the way he argued his case, and the way the mathematical model was able to fit with a wide range of experimental data.

Many ideas that scientists have turn out to be much less valuable than this insight of Newton’s. However, science relies on creative scientists having imaginative ideas that can be explored and developed – even if only a minority of them turn out to be really revolutionary.

The prepared mind

So part of being a successful scientist is using your imagination to generate potentially useful ideas. This is a creative process, and so it is not possible to ‘force’ an idea – and this is where many scientists (and other creative people) have found the idea seems to ‘pop’ into their mind when they are relaxing or doing something mundane (like the washing up perhaps!) Yet, this does not mean that having good ideas is just down to luck, or being lazy. The best ideas normally come to those scientists who have worked very hard to study a problem and learn as much about it as possible. As the French biochemist Louis Pasteur observed, ‘chance favours the prepared mind’: knowing about your topic in detail makes it much more likely you will have a useful creative idea.

In other words, creative ideas are the result of some kind of brain processing, 'thinking' if you like, but thinking at some subconscious level. Scientists do not yet really understand how this works, although here are some ideas that might turn out to be helpful:

1) ***hunches*:** we all know that people sometimes have a 'hunch' – an idea that they are confident in, as being more than just a guess, even though they can not explain the *grounds* upon which they think they 'know' – the 'just know'. This could well be the result of the brain in some way integrating information at some subconscious level, and presenting the results to consciousness. This is similar to the way *geneticist* **Barbara McClintock** described the way here brain was able to understand what was going on in her maize experiments. She trusted her brain to be processing information, integrating, even though she was not aware of the thinking process.

2) **neural nets:** scientists have discovered that it is possible for fairly simple networks of nerve cells (or electronic components that can be connected in similar ways) to 'learn' from experience without needing any awareness of what they are doing. For example, a simple neural net can be 'trained' to recognise when sonar reflections are from submarines (rather than shoals of fish for example) - by providing feedback about whether the output is accurate. At first the classifications are just random 'guessing', but by changing the connections according to which patterns give the 'right' answers it is possible to gradually increase the accuracy of the system.

   The **feedback** leads to changes in strength of the connections between neurons, and can lead to a very accurate processing: but the neural net has no 'idea' what a submarine (or sonar) actually is! It is possible that part of the way our brain works is like this. For example, a young child will learn to balance and walk by the feedback from trying to stand up and walk – the child does not consciously think about the signals it sends out to its different muscles. This is an area that scientists are only just starting to explore in detail, and much more research is needed.

3) **female intuition?** You may have heard of 'female intuition' – the idea that women can often 'sense' things that men miss. To the extent that this is a real phenomenon, there could be many reasons for this – for example the different things that boys and girls are encouraged to be interested in and take notice of when growing-up. However, one

interesting idea is that there is a physiological basis for women's intuition. Each of us actually has two brains, in the sense that each hemisphere can work independently to some extent, and - in most people – there is some degree of specialisation, with different hemispheres taking the lead for different types of tasks. There are differences between people (so some research suggests that women's hemispheres seem to share functions more than men's), but generally most people have common patterns in how their brains are organised. Amazingly, it is often possible for the brain to reorganise if part becomes damaged, although this takes time and is much more difficult for older brains. One three year-old epileptic boy had a whole hemisphere removed at age three, but developed a normal IQ.

There are large numbers of nerve fibres connecting the two hemispheres, which allow them to work effectively together. At one time surgeons tried cutting these fibres in people with very serious epilepsy that threatened their lives. This cured the epilepsy, but at a significant cost. The patients effectively had two independent brains, so, for example, the left-brain would not know what was in the left hand (as the nerve signals from the left side of the body feed into the right brain, and the right brain had no way of telling the left brain). It has been found that females tend to have more connections between their hemispheres than men, perhaps making them better at tasks that require the brain to integrate information from a range of sources? (Perhaps this also helps women 'multi-task'? Perhaps a lower level of communication between the hemispheres in men makes them better at concentrating without being distracted?) Again, a lot more research is needed to find out if these ideas are supported by real evidence.

4) **the modular mind:**. The brain has a very complex organisation, so that some tasks seem to be specialised in particular locations, but others, such as memory traces, seem to be spread around several parts of the brain. One theory suggests that the parts of the brain responsible for 'high-level' processing have evolved 'modules' to deal with different domains of knowledge. So, for example, young children develop knowledge of language, as well as what is sometimes called 'intuitive' (untaught) ideas about the thinking of others; the way objects move in the word; and the nature of animals and plants. It has been suggested that these 'domains'; of naïve physics, naïve psychology and naïve biology are to some extent localised in the structure of the brain. It has also been suggested that at some important point in the evolution of the brain, a new general purpose module developed that allowed us to take ideas from one domain and copy them to see how they fit else where. In others words, we learnt to think analogically – to think that

a brain is like a computer, or an atom is like a tiny solar system. This ability would allow the brain to make creative connections, such as Newton seeing the moon's orbit as being like the apple falling in some way. Again, scientists need to do a lot more research before we really understand if these ideas can help us understand how our brains really work.

What is learning?

We might describe learning as a change of behaviour, in response to experience – like the toddler learning to walk through trial and error. Some form of learning is characteristic of living organisms. **Pavlov** trained a dog to salivate when it heard a bell, by ringing the bell each time the dog was fed – eventually the sounds of the bell alone was enough to get the dog's salivary glands to start producing saliva ready to chew food – even though none was provided! (We might think it would have been more useful to train dogs *not* to dribble!)

Humans undertake something that most living things do not - deliberate learning, such as learning to drive or preparing to pass exams. When we learn there are changes in our brains, so that we will respond differently to experience in the future.

Meaningful and rote learning

One important distinction is between what is known as rote learning (learning by heart) and meaningful learning – learning through understanding. We can all learn some random 'non-sense' information if we repeat it enough, but it is difficult to learn a great deal of non-sense material. There are ways of training ourselves to get better at this, and occasionally there are people who seem to have perfect memory. The Russian psychologist Luria wrote a book about a patient who never seemed to forget anything – he cold remembers long passages or unfamiliar mathematical formulas he had heard only once, years before. However, he did not understand very much of the material he learnt, and was not able to hold down a regular job. In the end, the poor man killed himself.

For most people, though, it is much easier to learn something if we understand it. Understanding means that it makes sense in terms of what we already know. If we think about our existing knowledge of the world as a large network of ideas, it is important to see where any new information fits. If we can fit it in, anchor it to part of what we already know, then we are more likely to remember it. This is called 'meaningful' learning. Meaningful learning is easier when we actively work with ideas, rather than just try to 'commit' them to memory. So, for example, rewriting something in our own words makes us think about the meaning, whereas copying could just be a mechanical process. The more we can work with ideas, transferring them from one format to another, applying them in different contexts, the more likely we are to develop retain a good understanding. In science, information is presented in a wide range of formats, so there is plenty of scope to convert information between prose, bullet points, maps, charts, tables, graphs, diagrams etc.

However, even understanding something does not ensure it will be recalled when we need it. Learning new information leads to changes in the structure of the brain - i.e. new connections may be made between neurons, but often these changes are quite limited at first. (This makes sense – it would not be sensible for our brains to have evolved to totally change the way we think every time we experience something new). Just like Pavlov's dog, we need to have the learning reinforced if it is to lead to significant changes in behaviour (like easily remembering the information we need for an exam).

Much of the research into learning has used animals, or has concerned experiments with people trying to learn random lists of nonsense words, and we should be careful in interpreting this research when we are concerned with meaningful learning. That proviso notwithstanding, experiments suggest that:

- when we sit down to learn a lot of material, we tend to do better at remembering the first and last pieces of information – things in the middle are harder to recall;
- most material is soon forgotten if we only have one learning session; but repeat sessions increase the amount remembered each time, especially if they are times optimally;

As the brain consists of such a highly connected set of neurons, it seems to be good at representing knowledge as a highly interconnected set of ideas. It is believed that we can use this when we try to learn new ideas: the more we can find ways to connect the new information to existing ideas, the more new connections we set up, and the more 'access' routes we have to that knowledge in the brain.

These connections can be very powerful tools to aid recall. The author Proust wrote a major novel based around the memories provoked when the story's narrator experienced a familiar smell. We are not usually aware of some of the connections that our brain is making when we are learning; but it has been found it is sometimes easier to remember things if we try to recall them in the same room, or listening to the same piece of music, etc. (unfortunately this does not help us much with exams – unless we can take them at home with our favourite revision music playing).

Learning style

Some research suggests that different people have different ways that they prefer to work with information when they are learning (‘*learning styles*’) and even different ways they prefer to think about ideas and problems (‘*thinking styles*’). If this is correct, we might learn more effectively when we match learning experiences to our own styles. However, as the brain has several ‘input channels’ it also makes sense to try to develop strengths in learning from different types of information and experiences. One set of ideas about learning styles, for example, suggests that some people prefer to *see* information, and others prefer to *hear* it. Some people seem to learn better in a quiet place, others seem to work better when there is movement or music present. Some people prefer to work through ideas step by step – and other prefer to start with the overview and then fill in the details. As variety helps keep our concentration and interest at high levels, it is probably useful to know how we learn best, but also to use different ways of learning,

Multiple intelligences?

Sometimes learning styles are linked to the idea of ‘*multiple intelligence*’. Different researchers disagree about how to understand intelligence. Some see the human brain as being based around a central purpose processor – which draws upon information from different parts of memory as it needs them. Other researchers think the brain is better understood in terms of a set of largely independent components working together. In this model there are different circuits in the brain responsible for different types of ‘intelligences’: so, for example, some people might be good at maths, but poor at relating to others, because of which parts of their brain are highly developed.

There is lot of evidence that brain damage often produces specific deficits – for example a stroke might lead to someone losing the names of objects, whilst the rest of their language was unimpaired. However, it may be that the brain is much *more complicated* than this - and that the extent to which different abilities are localised may vary greatly across different abilities (or perhaps even across different people).