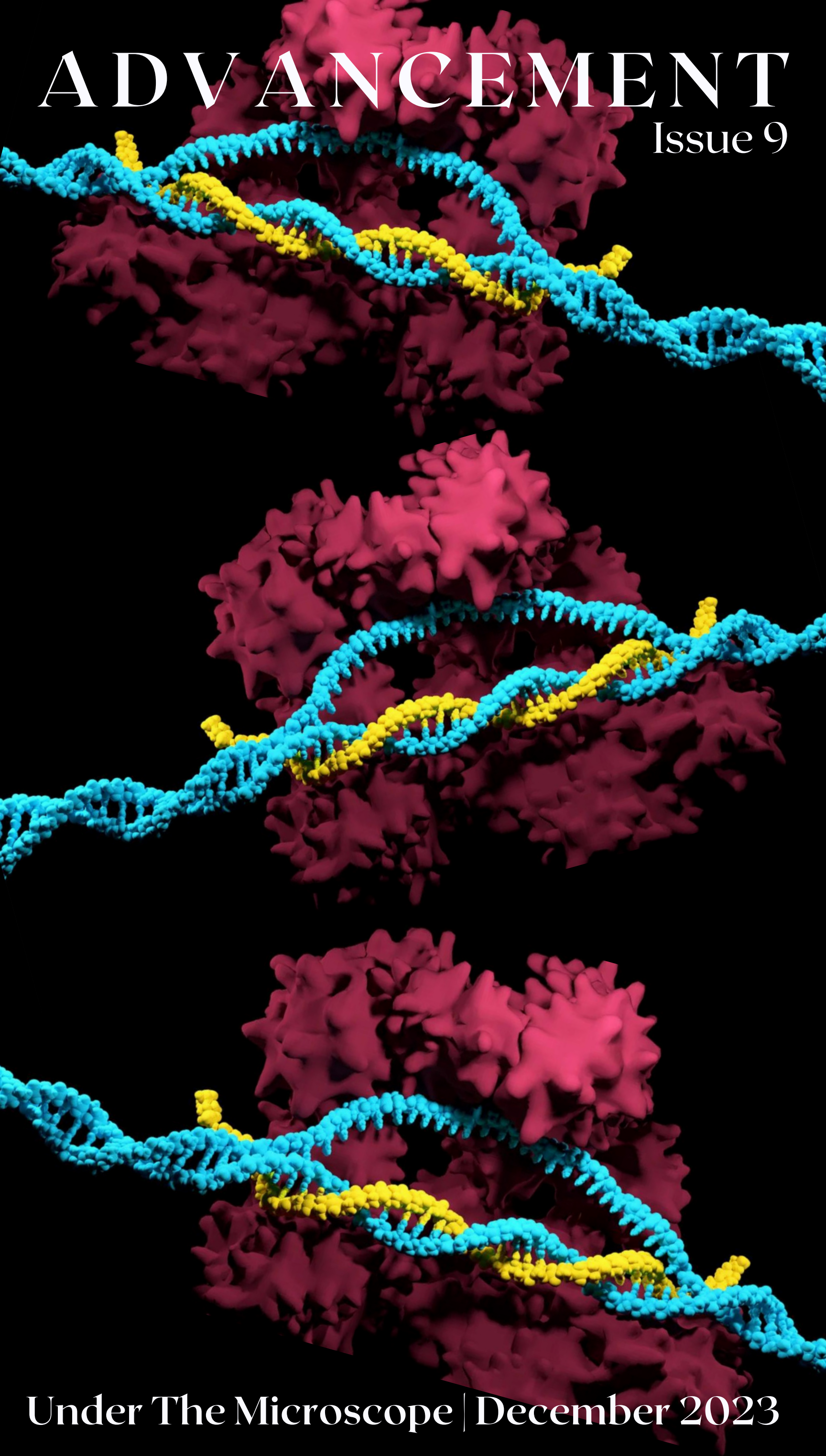
ADVANCEMENT

Issue 9



Under The Microscope | December 2023

Editors' note

We are thrilled to introduce Issue 9 of Under the Microscope! As always, we were really impressed by the standard and range of articles, all coming under the theme of Advancement. There are a variety of interesting topics to read such as vaccines against cancer, how women have contributed to maths and green hydrogen technology, so we hope you enjoy! We were especially happy to receive two interviews for our features section, so remember to take a look at Professor Quinn's expert opinion on investigating birds and their evolution and Dr Ameku's interesting experiments and research on the intestines!
We hope you enjoy looking at some of the fascinating articles and opinions on STEM and wish the new team for Under the Microscope the best of luck for next year!

SORA:
Features editor (gets fun and original content for the magazine).

TILLY:
Commissioning and Development editor (helps get as many articles from across the school as possible).

RAWNAQ:
Copy editor (reads through each article to ensure scientific accuracy and that each one is an enjoyable read).

LAILA:
Editor in chief (helps to organise the team to make sure everything is going to plan).

GHAZAL:
Copy editor (also reads through each article to ensure scientific accuracy and that each one is an enjoyable read).

CLARISSA:
Creative editor (puts all the articles together to form a cohesive whole in an exciting format and designs the front cover).

Contents:

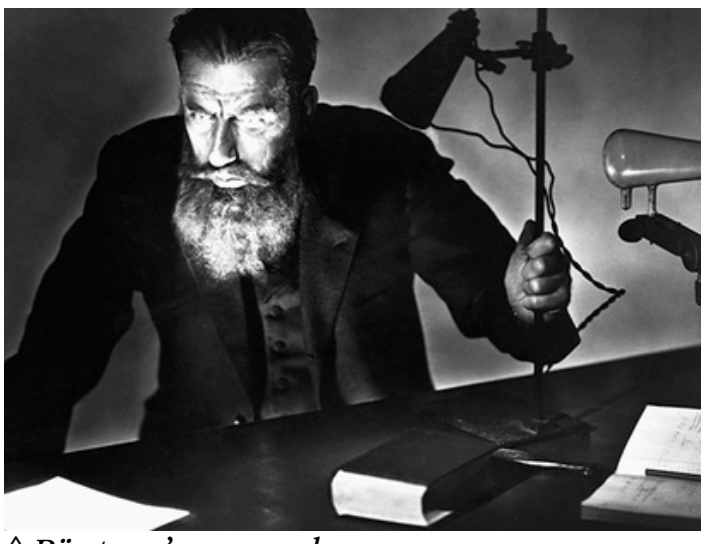
Features:

X-Rays: Beneath the surface

By Mollie Patterson

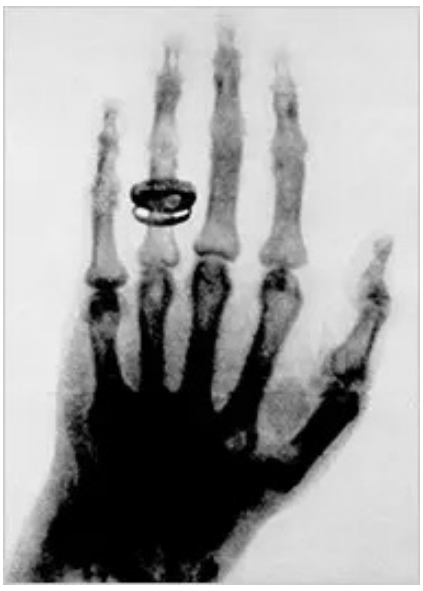
X-rays offer a quick and painless insight into the internal structures of the body; within medicine, this form of imaging is routinely utilised to make diagnoses ranging from that of a broken bone to cases of pneumonia. X-rays have transformed everyday medical practices, yet, shockingly, their discovery was completely by accident.

In 1895, Wilhelm Röntgen, a professor of Physics in Wurzburg, was carrying out work regarding cathode rays: beams of electrons emitted from a negatively charged electrode. The tube itself consisted of a glass bulb that enclosed positive and negative electrodes. When a vacuum was generated within the tube and a high voltage was applied, the tube would produce a fluorescent glow. Even with the cathode-ray tube shielded with heavy black paper, a green, fluorescent light was still given off by phosphorescent materials (materials that give off light when exposed to radiation) located near the tube. From this, Röntgen concluded that a new type of ray was being emitted from the tube and that this ray could pass through the heavy paper covering- as he did not know what the rays were, he called them 'X-rays.'



^ *Röntgen's research*

Following some subsequent experimentation, he found that the new ray could pass through most substances and would cast shadows of solid objects. This discovery also led to Röntgen to realise that the ray could pass through the tissue of humans, but not bones or metal. One of Röntgen's first experiments late in 1895 was a film of the hand of his wife, Bertha, with her metal wedding ring clearly visible.



^ *An 1896 X-ray by Röntgen*

Röntgen's work held scientific and public interest alike, the apparatus for producing X-rays was made widely available and studios were rapidly opened to produce "bone portraits." Whilst the prospect of X-ray glasses daunted members of the wider public, the medical community quickly recognised the importance of Röntgen's discovery. By February of 1896, just one month after Röntgen's first public presentation of his research, X-rays were first used in a clinical setting to image fractures. Attempts to image vessels and organs using X-rays soon followed, typically by inserting a metal rod or injecting a radio-opaque substance into the structure to create a clear image. The advances made by Röntgen earnt him the Nobel Prize in Physics in 1901.

Since the early developments of the 19th century X-rays, along with other imaging techniques, have maintained their status as an invaluable tool for medical practice.

Should Free Healthcare be Provided for Everyone?

By Laila Samarasinghe

Free healthcare is something many of us take for granted in the UK. It seems like such a basic right to us that we forget those in other countries who often struggle to pay for treatments or do not get care at all. Unfortunately, it is not always possible to offer this service. I am going to look at some of the financial and ethical pros and cons for offering free healthcare.

One of the core values in the NHS is to provide equal and accessible treatment to everyone, regardless of socioeconomic standing. This allows healthcare workers to take justice into account, as the GMC requires, so that all patients receive the same standard of care. In a system where only those who can afford healthcare are treated, the medical industry becomes more discriminatory against those who cannot pay. Furthermore, it is intrinsically more corrupt as doctors are motivated by money instead of standard of care.

^ *NHS values*

When healthcare is free, more people use it. A benefit of this is that people are more willing to seek help if they believe there could be a problem. As a result, more illnesses are spotted early, and their progression is reduced or prevented. This can benefit society if communicable diseases are treated before they spread. On the other side, it could be argued that it makes people feel more inclined to get medical attention for small issues which would easily go with time and rest. This is potentially problematic in a time where hospitals are understaffed and there are limited resources to go round.

Free healthcare has many advantages, but some are against it because of its costs to run. It requires a lot of funding, especially with many of its patients being chronically ill and needing a lot of care. It is viewed as unfair by some people that this is funded by their taxes when they rarely benefit from it. On the other hand, this may be less than the cost of health insurance or the hospital bills when treatment is eventually required in places without free healthcare.

An alternative system to free healthcare for all has been suggested in the past. This would include free healthcare for some, but not for those whose lifestyle choices caused their ill health. For example, those who have lung cancer caused by smoking or heart disease caused by lack of exercise and poor diet would pay. On the surface, this may solve some of the problems caused by a free health service. There may be fewer patients and it could make the public be more active and eat better to avoid the high price of falling ill. However, people are not realistically going to change their lifestyles. They are more likely to just not seek help when they fall ill. Furthermore, this leads to a slippery slope of charging all people for falling ill if there were any lifestyle influences. Also, this goes directly against the medical ethic of justice – treating all patients equally, regardless of their choices in life. It would lead to a healthcare service that directly discriminates against patients, especially when certain demographics of society have less access to healthy food, clean air and education about healthy lifestyle choices.

In conclusion, it is important to provide treatments for free in every situation. A healthcare service where patients are charged favours the health of those with more money, which goes against medical principles of fairness. As shown by other countries, this is not always possible or prioritised. However, I am in favour of providing free healthcare to maintain a service based on patient best interests instead of patient wealth.

Advancements in gene-editing technology: Exa-cel: The first CRISPR gene-editing machine submitted for FDA Approval

By Ysaline Pauwels

Introducing CRISPR-Cas9

Genome editing (gene editing) is a group of technologies that give scientists the ability to change an organism's DNA. These technologies allow genetic material to be added, removed, or altered at specific locations in the genome. Several approaches to genome editing have been developed, one being CRISPR-Cas9 (short for clustered regularly interspaced short palindromic repeats) and CRISPR-associated protein 9. This modern technology has generated excitement in the scientific community as it is faster, cheaper, more accurate, and more efficient than other genome editing methods.

CRISPR-Cas9 was adapted from a naturally occurring genome editing system that bacteria use as an immune defence. When infected with viruses, bacteria capture small pieces of the viruses' DNA and insert them into their own DNA in a particular pattern to create segments known as CRISPR arrays. These allow bacteria to 'remember' the viruses (or similar ones). If the viruses attack again, the bacteria produce RNA segments from the CRISPR arrays that recognise and attach to specific regions of the viruses' DNA. The bacteria then use Cas9 or a similar enzyme to cut the DNA apart, which disables the virus.

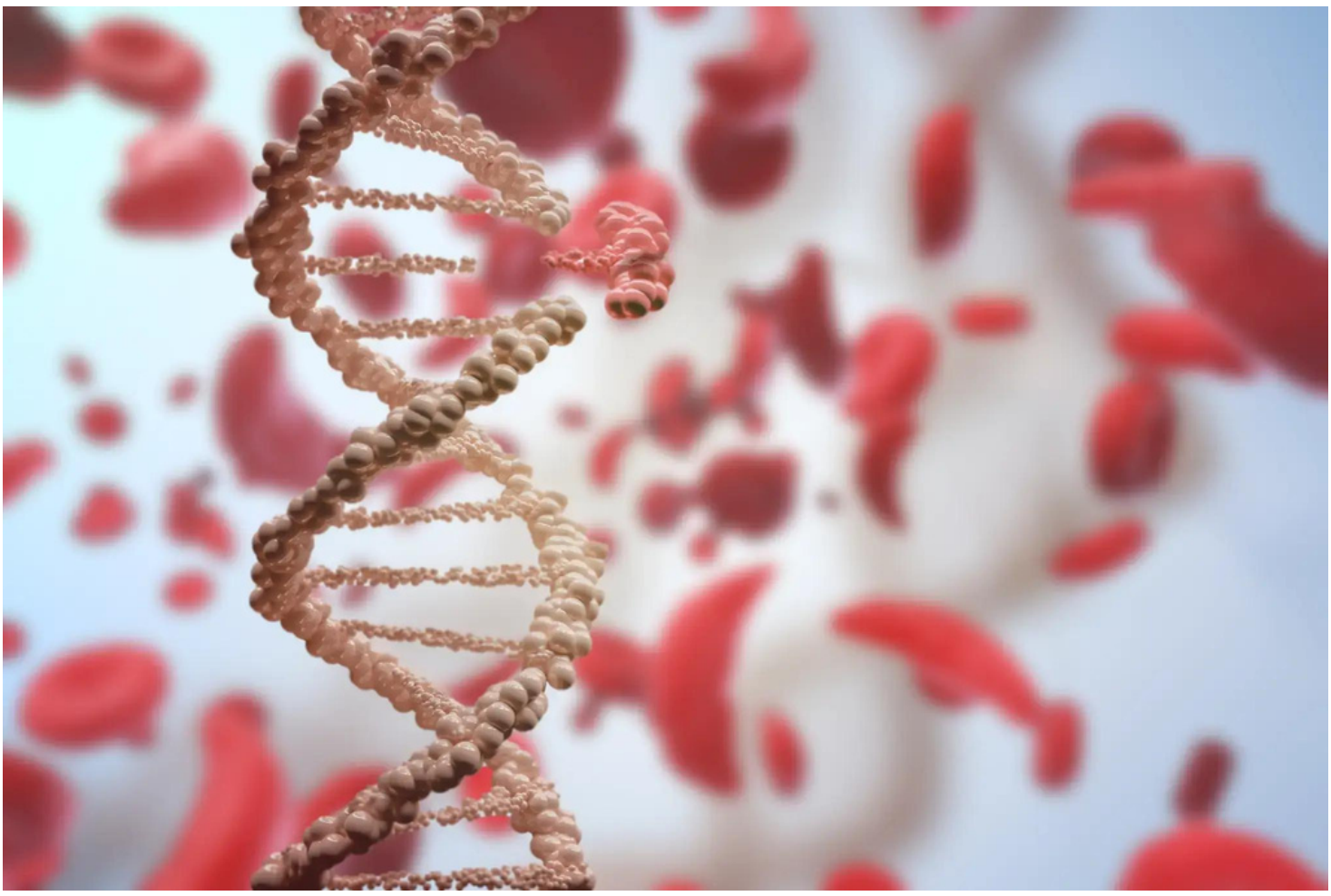
Genome editing is of great interest in the prevention and treatment of human diseases such as sickle cell disease, cystic fibrosis, and haemophilia. It also holds promise for the treatment of more complex diseases, such as cancer, HIV, and heart disease. Currently, it is being used in cells and animal models in research labs to understand diseases. However, scientists are still working to determine whether this approach is safe and effective for use in people. For example, changes made to genes in egg or sperm cells or to the next genes of an embryo could be passed onto future generations.

A treatment for sickle cell disease?

Exagamglogene automcel (known as exa-cel) is aiming to be a new and improved way to treat sickle cell disease (SCD) and beta thalassemia, with a one-dose treatment. SCD and beta thalassemia are genetic conditions that change the way your blood behaves. Specifically, they interfere with haemoglobin and its ability to carry oxygen throughout your body. Haemoglobin is a fundamental component of your red blood cells, so its deficiency can lead to several problems if left untreated. This means these conditions are hard to treat. To tackle them, healthcare providers need access to new medications that can correct the genetic issues at fault, which is what exa-cel aims to do.

Exa-cel is a gene therapy medication that is in advanced stages of development. Being a gene therapy medication, exa-cel edits the genetic makeup of certain stem cells in your body. Stem cells are taken from your body, genetically modified in a lab, and reinjected into your body as a form of treatment. At the lab, scientists use CRISPR-Cas9 gene editing. CRISPR acts like a detective that can identify problematic genes and can install new or improved DNA. In this case, a gene called BCL11A, that would normally tell your body to stop producing haemoglobin, is cut into. This will activate your body to make more haemoglobin as a result. Higher amounts of haemoglobin are said to help improve length of life for people with SCD. Exa-cel modifies stem cells so they can learn how to make healthy, oxygen-carrying haemoglobin. For SCD, this could mean fewer abrupt pain episodes and better symptom control. For beta thalassemia, it could make blood transfusions a memory of the past. Zynteglo is the first gene therapy medication already approved for beta thalassemia, but exa-cel uses a more unique technology.

So far, everyone with SCD has reported being free from pain episodes after receiving exa-cel. Over 90% of people with beta thalassemia were able to quit blood transfusions within three years of their infusion. These studies only included people with ages from 12 to 35, but other studies are analysing the benefits and risks of exa-cel in children as young as 2 years old. A long-term study planning to track those who receive exa-cel for up to 15 years is also taking place to witness progress. A recent study has shown that the estimated life expectancy of adults with SCD is 54 years, which is approximately 20 years shorter than that of normal adults without SCD. With a total of 376,000 sickle cell disease deaths in 2021, a new and improved treatment such as exa-cel would be life-changing for many.



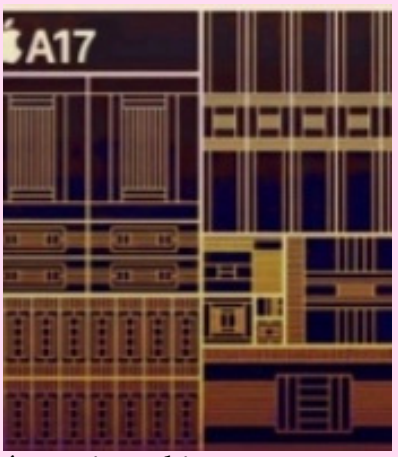
The Most Manufactured Device in History

By Zoe Thomas

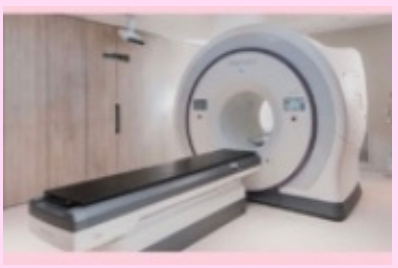
Transistors are arguably the most important invention in history. You find them in almost every electronic device and they have played a critical role in revolutionising modern technology as they are the foundation of so many devices. They are made of semiconductor material and have three terminals (collector, emitter, and base) for connection to an electronic circuit. The third terminal controls the flow of electricity between the other two. It can be used to take a weak signal, such as a radio wave in the air, and turn this into a strong signal (for example, to power a music speaker).

^ *Model of the first transistor*

Transistors are used in a wide variety of fields for a diverse range of purposes. For instance, in communication and telecommunication, they are used in radios, televisions, mobile phones, wireless networks, GPS, and they amplify and transmit signals allowing us to communicate in seconds with anyone around the world. Additionally, they are alsoimportant renewable energy resources, as they're found in wind turbines, solar panels, used to convert sunlight intoelectricity and they help optimise the performance of solar cells making them more efficient and cost-effective. We can also see them in modern medical innovations, being essential components of pacemakers, MRI machines, blood glucose monitors and enabling precise control and measurement of electrical signals ensuring accurate diagnosis and life-saving treatments.

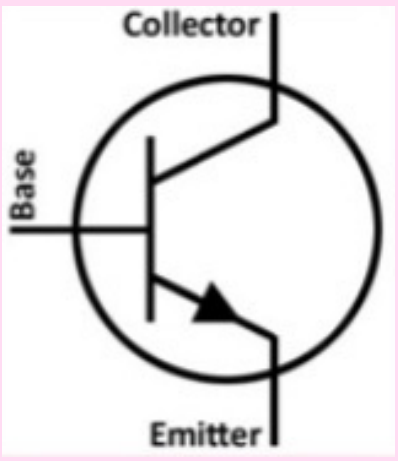


^*A7 microchip*



Transistors were invented in 1947 by three scientists at Bell Laboratories: John Bardeen, Walter Brattain and William Shockley. Initially, their prototype was quite large and expensive, but its design was soon developed. By 1955, they were even more powerful whilst also small and cheap enough to use in consumer electronics, replacing old fashioned valves. However, the rate of production was one transistor per 1000 people (essentially zero) but, as with thedesign, this also rapidly changed.

Around 1960, it became possible to put many transistors together into a so-called "integrated circuit" (also known as the first microchip). Now a microchip such as the A17 in the new iPhone 15 has 19 billion transistors in one chip and the company who designed the chip is worth 54 billion dollars! In 1965, the rate of production had now increased to one perperson per year as radios became hugely popular, then just ten years later in 1975 it was nearly 1500 per person per year and by just 1985 global production of transistors had surpassed 40 thousand per person per year. By 2000, it was 65 million and today it is 56 billion! The world now produces more transistors in one second that it did one year in 1980. This advancement in the production of transistors has enabled them to play a huge role helping our gadgets function, improving our lives and contributing to the progression of technology.

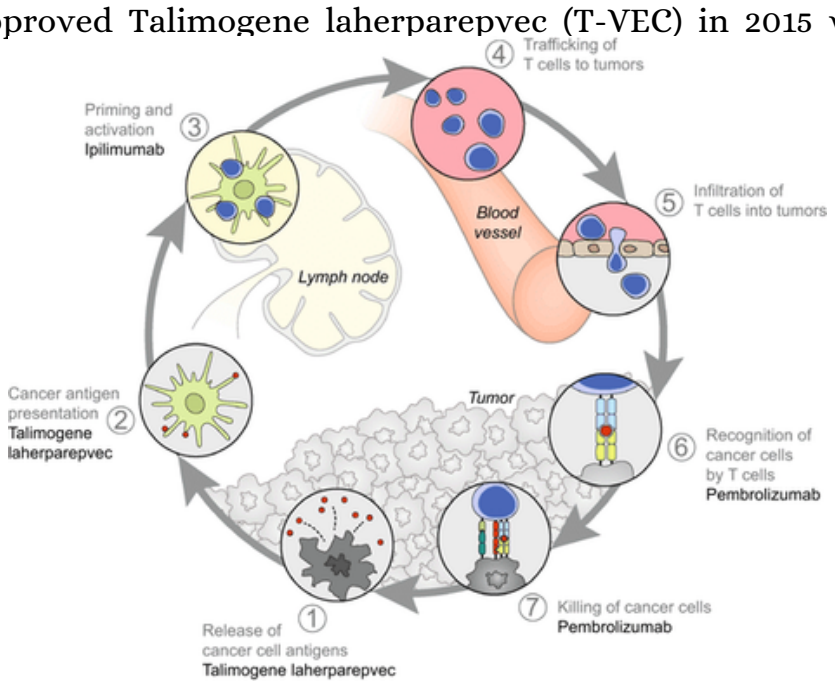


From COVID-19 to Curing Cancer: The Advancement of mRNA Vaccines

By Ghazal Ershadi-Oskoui

Vaccines are used to provide individuals with long-term immunity to certain diseases. They generally work by activating the body's immune system to make its own antibodies against a safe form of an antigen which is injected into the bloodstream. These foreign antigens trigger the primary immune response, resulting in the body producing antibodies and memory cells. If the individual encounters the specific antigen again, the secondary immune response is triggered so that the pathogen is destroyed rapidly before it can spread and symptoms are displayed. Cancer is a leading cause of global deaths (responsible for almost 10 million deaths in 2020/nearly one in six deaths). Therefore, a cancer vaccine would be an excellent solution to this ever-growing problem.

Since April 2010, when the first ever cancer vaccine (Provenge) was approved by the US Food and Drug Administration, a vaccine for cancer has been becoming increasingly realistic. Provenge is not very widely used as it is extremely expensive, with a single course costing around $100,000. Other cancer vaccines have been developed but have been unsuccessful. Unlike vaccines protecting us from disease, cancer treatment vaccines are for people who already have cancer. However, some cancers are associated with viral infections; the most well-known example of this is the human papillomavirus (HPV) vaccine, which the US Centres for Disease Control and Prevention says can prevent around 92% of cases of cancer associated with HPV in the US yearly. Viruses can also be used to induce an immune response against cancer (known as oncolytic viruses): the FDA approved Talimogene laherparepvec (T-VEC) in 2015 which is used against melanoma.



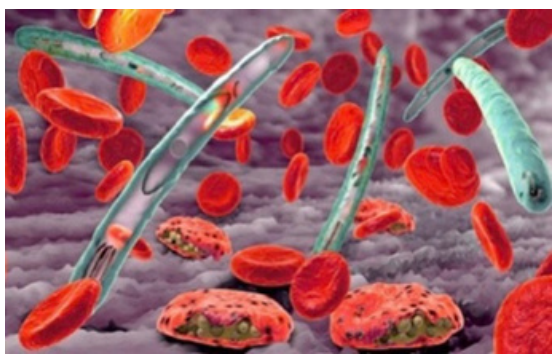
^*mechanism of action of Talimogene Laherparepvec (T-VEC)*

The issue with making a cancer vaccine is choosing what antigen to present to the immune system as it must be one that does not trigger an attack on healthy tissues and yet it should also be sufficiently represented by the tumour to activate a comprehensive immune response (i.e., tumour specific antigens (TSAs)). It is difficult to identify an antigen which does this; Alan Melcher, lead of the Centre for Translational Immunotherapy at the UK's Institute of Cancer Research, says, "We still don't know enough about the antigens that really matter and those that really don't." According to Melcher, the key is to target the antigens which are present at the origination of the tumour (or, as he puts it, "in the trunk of the tree") rather than antigens that have developed in isolated parts of the tumour later ("the branches" of the tree) as these will be more widely present. Additionally, another issue is that cancers mutate and spread very rapidly and at varying rates so a personalised vaccine which targets TSAs could soon become ineffective if the individual's cancer mutates or spreads.

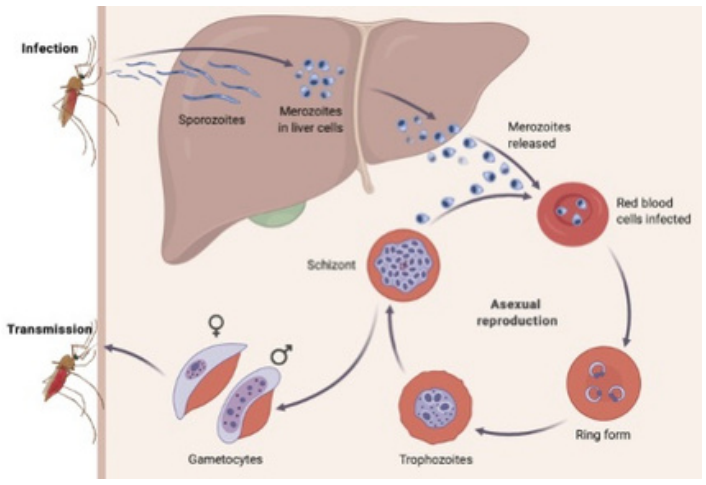
Advancements in Malaria Medication: Artemisinin-Based Combination Therapies

by Rawnaq Islam

Malaria is an infectious disease caused by the parasitic protoctist *Plasmodium falciparum*. It is transmitted to humans through the bite of infected female Anopheles mosquitos, which act as vectors. Malaria affects millions of people every year, primarily in tropical and subtropical regions, and is characterised by symptoms including a high temperature, chills, sweats, and muscle pains. Unfortunately, if it is left untreated, malaria can be fatal. The disease remains a persistent global health concern, and while preventive measures such as insecticide and bed nets have played crucial roles, Artemisinin-based Combination Therapies (ACTs) have been a key advancement in the ongoing treatment of malaria.



Early attempts at creating a treatment for malaria included the use of quinine, an alkaloid derived from the bark of the cinchona tree, which can be found in South America. Quinine was historically used as a standard treatment for various forms of malaria in the 19th century; however, it had undesirable side effects, which included blurred vision and hearing loss. But while quinine was a somewhat effective antimalarial, the emergence of drug-resistant strains of *Plasmodium falciparum* was later revealed to be a significant limitation of quinine. This prompted researchers to seek more effective and safer alternatives, leading to the development of artemisinin.



Artemisinin is a drug derived from the plant *Artemisia annua*, also known as sweet wormwood. While artemisinin is highly effective on its own due to its potent antimalarial activity, it is often used in combination with two or more other antimalarial drugs, forming ACTs. The choice of partner drugs is strategic, as they target the parasites at various stages of their lifecycle. Some partner drugs focus on the early stages of the parasite's lifecycle within red blood cells, while others may target the liver stage, where the parasite initially multiplies following infection.

ACTs' mechanism of action can be simplified into two main stages. First, artemisinin quickly targets the parasites that are present in the bloodstream; using its unique structure, artemisinin then breaks down the parasites' cell walls, effectively destroying them. This stage is what provides the quick relief from the malaria symptoms. In the second stage, the partner drugs continue to attack any remaining parasites, to prevent the malaria from recurring. This dual-action approach ensures the parasites are rapidly cleared and minimises the likelihood of the parasites developing drug resistance.

ACTs have played a pivotal role in reducing the spread of drug-resistant malaria parasites, with a notable 51% reduction in malaria-related deaths globally from 2000 to 2019, according to the World Health Organisation. It is clear ACTs have had a profound impact on treatment outcomes, but despite their effectiveness, ACTs face challenges such as accessibility, affordability, and the potential emergence of artemisinin resistance. Hence, it remains crucial that research and global efforts continue in order to continue delivering promising solutions against this persistent disease.

Mathematical Biology in Epidemology

By Sora Kamide

Mathematical biology, also known as biomathematics or theoretical biology, is an interdisciplinary field that uses mathematical and computational methods to model and analyse biological processes. It aims to describe, understand and predict the behaviour of biological systems by applying various mathematical areas, such as calculus, probability theory, statistics, linear algebra, topology, differential equations and more.

Some key applications of mathematical biology include population dynamics, cellular and molecular biology, evolutionary biology and medicine. I would like to introduce one area where mathematical biology is applied - epidemics.

Mathematical biology is used in epidemiology, to study the spread of infectious diseases, to predict disease outbreaks and assess the impact of interventions such as vaccination and social distancing.

For example, during the COVID-19 pandemic, mathematical models such as SEIR (Susceptible-Exposed-Infectious-Recovered) and SIR (Susceptible-Infectious-Recovered) models were used to predict the spread of the virus. These models helped to estimate parameters such as the basic reproduction number (R0), an epidemiologic metric used to describe the contagiousness or transmissibility of infectious agents, and also evaluate the impact of various interventions, including social distancing, mask-wearing and vaccination.

The SEIR model works by dividing a population into several compartments based on the individual's disease status. S (susceptible) includes individuals who are not infected but are at risk of contracting the disease. E (exposed) represents individuals who are infected but cannot yet transmit the disease to susceptible individuals. I (infectious) are individuals who are infected and can transmit the disease to susceptible individuals. R (recovered) accounts for individuals who have either recovered from the disease or have died and therefore, do not contribute to the spread of the disease.

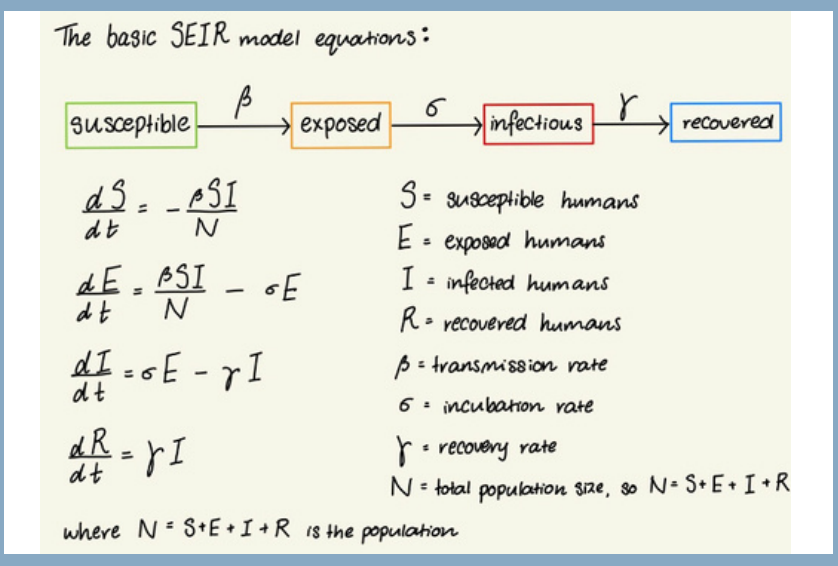
These compartments are then plugged into differential equations that describe the flow of individuals between these compartments over time, given that differential equations describe the function's rate of change. These equations are based on several parameters: the transmission rate (β), the rate at which an infected individual transmits the disease to a susceptible individual, the incubation rate (σ), the rate at which individuals in the exposed compartment becomes infectious and the recovery rate (γ), the rate at which infectious individuals recover or die.

These equations describe how as the disease spreads, individuals move from the susceptible to the exposed component, from the exposed compartment to the infectious compartment, and from the infectious component to the recovered compartment.

The SEIR model helps to understand the dynamics of the disease, predict disease trends, assess interventions (such as vaccination, social distancing and quarantine measures), monitor outbreaks and many more. It has helped guide public health strategies, through working as a reliable tool.

The SIR model works in a similar way, but excludes the exposed compartment. However, through incorporating the exposed population (E), the latent phase can be estimated. The latent phase is the delay which occurs during which the individual is infected but not yet infectious. Such periods of time are very important when modelling diseases such as COVID-19, as individuals can transmit diseases before showing symptoms.

Overall, mathematical biology has made substantial contributions to significant scientific advancements in various biological fields. It helps direct complex questions and provides a quantitative model for studying biological phenomena.



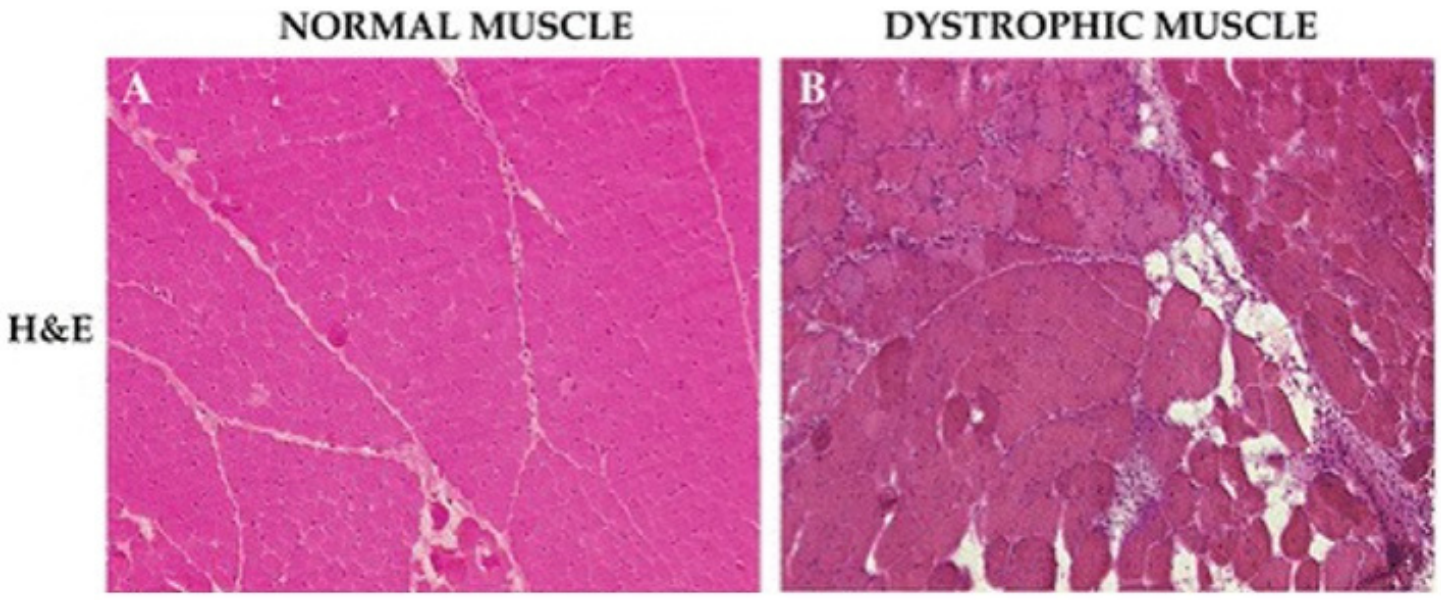
The Advancement in the use of Gene Therapy to treat Duchenne Muscular Dystrophy

By Tilly Bowden

Duchenne muscular dystrophy (DMD) is a genetic disease caused by an inherited mutation in the largest gene in the human body, the DMD gene. This mutation affects the muscles and their ability to contract, meaning a person with DMD will suffer from a progressive loss in muscular function which is eventually fatal.

DMD is passed on in an X-linked recessive fashion, meaning that it is passed on through an X chromosome. Therefore, the disease is mainly found in boys, because to have the disease they must inherit a Y chromosome from their father and a mutated X chromosome from their mother. However, for a girl to have the disease they must inherit two mutated X chromosomes, one from their mother and one from their father. Approximately 2500 people in the UK have DMD, with a ratio of one female to six thousand males worldwide.

The DMD gene codes for the protein dystrophin which is a cytoplasmic protein found in the sarcolemma (the plasma membrane of muscle cells). However, a person with DMD has a frameshift mutation on this gene, meaning that the stop codon comes sooner in the sequence which means the protein is incorrectly coded for. Therefore, a patient will lack the dystrophin protein, impairing muscular function. Dystrophin usually helps stabilise the muscles during contraction when stress is placed on the sarcolemma. However, if there is a lack of dystrophin, a person will suffer from contraction-induced damage to their muscles, which will weaken them and make the sarcolemma more susceptible to damage. This leads to myonecrosis (death of muscle fibres), which stimulates the muscle fibres to regenerate. However, a DMD patient lacks the dystrophin which would form to help strengthen the muscle so, instead, it is replaced by non-contractile tissue, which further exacerbates its function. This muscular degeneration occurs in muscles throughout the body (from skeletal muscle to cardiac muscle) meaning the entire body of a patient is affected. The largest issues are caused when the intercostal muscles and diaphragm degenerate, impairing a patient's breathing, and when cardiac muscle degenerates (which stops the heart from beating properly).



Furthermore, dystrophin is thought to play a role in cell signalling, particularly involving calcium ions entering the muscle. This is because the sarcolemma is where calcium ions enter and leave the muscle cells. At a neuromuscular junction, an action potential stimulates calcium ions to diffuse into the synaptic knob and causes vesicles to fuse with the presynaptic membrane and release their contents into the synaptic cleft by exocytosis. The neurotransmitter then diffuses across the synapse and binds to complementary receptors on the postsynaptic membrane and an impulse will be generated. However, a lack of dystrophin increases the permeability of the muscles to calcium ions, which causes too much calcium to enter the presynaptic neurone, thus the muscles are overstimulated, and a patient will get muscle spasms in the form of twitches and cramps.

However, these symptoms can be reduced or potentially eliminated using gene therapy. Gene therapy for DMD has involved gradual development up until the point where in August of this year, a 5-year-old boy in the US became the first DMD patient to receive gene therapy, using a therapy called ELEVIDYS (delandistrogene moxeparvovec-rokl).

Gene therapy has so far been used to treat diseases such as cystic fibrosis and haemophilia, yet the application to DMD has been difficult because of the size of the DMD gene, which is the gene we want to modify. It is 11.5kb (kilobases) long, yet the vector usually used for gene therapy, adeno-associated virus (AAV), only packages approximately 4.7kb. This means that scientists have had to create an AAV microdystrophin gene therapy, which involved removing some of the coding sequences of the gene to make it smaller and fit inside AAV, but still retain its function.

The gene therapy is delivered by an IV infusion to patients and works to reduce symptoms by providing some dystrophin to the muscles. To do this, the genetic information of AAV is modified. AAV consists of a protein coat which surrounds a single strand of DNA. This DNA was cut in two places, the middle was replaced by the microdystrophin gene. Then the virus was infused into the patients. Once AAV is inside the nucleus of a host cell, it sheds its protein coat and its DNA forms an episome which is a special type of plasmid that remains part of the host genome but doesn't integrate itself into the host DNA. This episome is then transcribed and translated to produce some dystrophin.

Clinical trials studying ELEVIDYS showed that the treatment increases the proportion of dystrophin in the body, but it hasn't been shown to improve motor function. Despite this, it was approved by the FDA under the accelerated approval pathway because of an "urgent unmet medical need". However, the FDA did specify that as a condition of this approval, Sarepta (the drugs company that manufactured ELEVIDYS) would need to conduct a clinical trial to prove it does improve motor function in the long term.

In terms of the future of gene therapy for DMD, many patients and their parents hope that new treatments can be developed to help children over a range of ages because ELEVIDYS is only approved for 4-5-year-olds. Furthermore, research into using CRISPR-Cas9 technology has been conducted, yet it is currently unable to be used because there are still some mutations in the DMD gene which CRISPR can't rectify.

Overall, patients and their parents seem optimistic about the future advancement of the use of gene therapy, with ELEVIDYS being called "a vote for hope". This is the first gene therapy ever for DMD patients, so with more clinical trials and research, it can hopefully be modified and developed to become even more effective in the future.

Advances in Natural Language Processing (NLP)

By Clarissa Soto-Rosa

What is Natural Language Processing (NLP)?

Natural language processing (NLP) refers to the branch of artificial intelligence (AI), within computer science, that is concerned with giving computers the ability to understand and interpret text and spoken words for the purpose of learning, understanding, and producing human language content.

NLP combines computational linguistics (rule-based modelling of human language), with statistical, machine learning, and deep learning models.

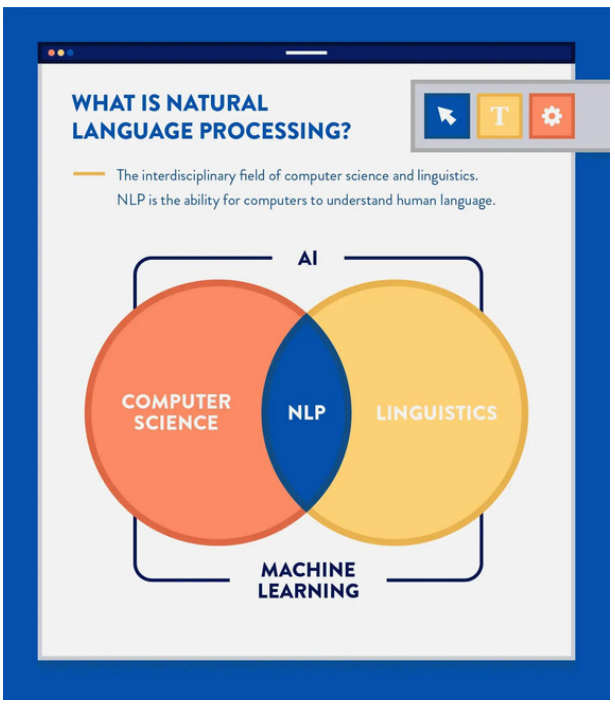
The evolution of NLP

Early computational approaches were used to develop basic technologies such as machine translation (MT) and speech recognition, by automating the analysis of linguistic structure of language. Today's research has increased real-world application, and is much more developed, particularly in terms of understanding ambiguities in language. This means that it can be used in more complex scenarios and is increasingly being incorporated into consumer products. For example, speech-to-speech translation engines, and extracting information from social media, being able to identify emotive language.

Four key factors have enabled this development:

1. A significant increase in computing power
2. The availability of large amounts of linguistic data
3. The development of highly successful machine learning methods
4. A much deeper understanding of the structure of human language and its deployment in social contexts

In other words, advancements in the understanding of both technology and linguistics.



The history of NLP

1950s-1990s

Machine translation was one of the first non-numeric applications of computers and was a key topic in research, beginning in the late 1950s. However, they had limited success due to the simple grammar-based systems that could not process large quantities of words.

Also, before the 1990s, complex, handwritten rules were used to understand text. This was inefficient – it was slow and expensive because of the impractical methodology, with too many details for programmers to track, so the code became too complex.

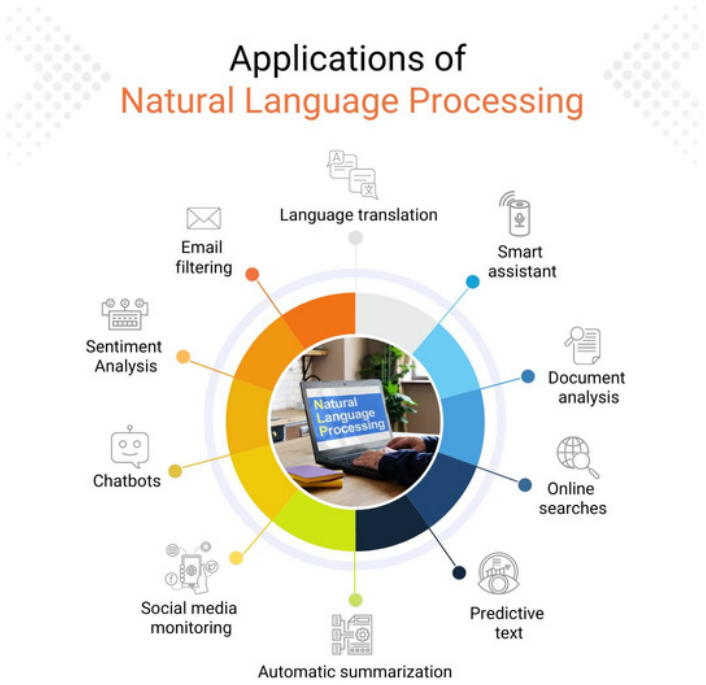
1990s

In the 1990s, algorithms evolved, and became based on probabilities and statistics. Words were matched with numbers to make sense of inputs and choose outcomes based on the best pattern match within the program.

Machine translation was massively improved in the early 1990s, when researchers at IBM acquired a large quantity of English and French sentences that were translations of each other (parallel text), produced by the bilingual Canadian Parliament. This allowed researchers to start building models using large quantities of empirical language data, leading to corpus ("body of words")- based NLP.

2000s

In the early 2000s, there was a much larger quantity of online parallel text, and cheaper computing available. This led to a change in corpus phrase-based machine translation systems, whereby, identifying the translations of smaller word groups which often have distinctive, not literal translations, began to be used (rather than translating word by word). Though this meant that the quality of translation improved, much of the following research has aimed to better understand the structure of sentences (their syntax) to continue to increase the accuracy of language.



2010s and 2020s

In the 2010s, the development of deep-learning-based sequence models allowed for the development of an improved approach to MT. Deep learning is based on the idea of training a model with several levels to achieve a final objective, such as translation quality, so that the model itself can learn intermediate tasks that are useful completing this. For example, there has been research into a particular version of computational networks, with enhanced long and short-term memory units, which can better maintain contextual information from early until late in a sentence. Spoken dialogue systems (SDS) and conversational agents have developed significantly since the 1980s, when they began to be a central topic in NLP. They require automatic speech recognition (ASR) to identify what has been said, dialogue management (DM) to determine what action needs to be taken to perform the task; and text-to-speech (TTS) synthesis, to transfer than information back into the human spoken form. Advancements in speech recognition accuracy, which have come primarily from replacing traditional acoustic identification models with deep-learning models that use sound signals to create sequences of human language sounds and words, have allowed for this significant improvement in speech recognition accuracy.

Although early work in NLP focussed on the development of simple yet highly scalable fact-extraction techniques that do not require individually labelled pieces of data, with every improvement in this field, there has been an increased emphasis on linguistic structure.

Though NLP has already come a long way in its applicability, such as in social media and in socially assistive robots, in the future development aims to produce even better responses, for example by exploring how an element of common-sense reasoning can be implemented into these models. In this way, they will have an increased understanding of cause-and-effect relationships.

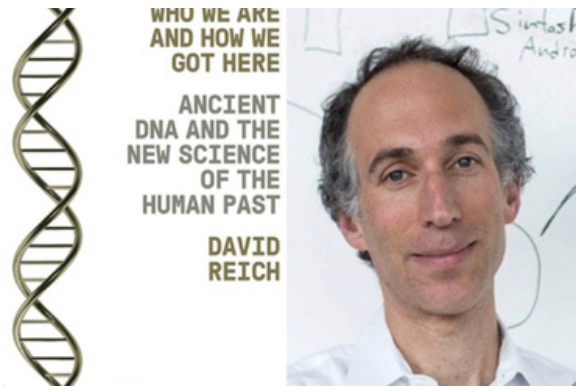
How Ancient DNA is contributing to Advancements Today

By Shana Hassanlou

Ancient DNA analysis has been a significant advancement in science and has greatly expanded our knowledge on evolution and species. This development has allowed us to also learn about the lives of the ancients and about extinct animals and more. Due to the rapid increase in development of technology, we can be sure that we can unlock more about this and learn more about our past.

Ancient DNA has provided us with insights on the understanding of evolution and phylogeny which conveys the evolutionary descent of different species and organisms. There have been many scientists who have compared the genetic material of ancient and modern species such as Professor David Reich from Harvard. Reich has been able to reconstruct the history of organisms, assembling five ancient human genomes and also sequencing more than 16,000 ancient humans around the world; this enabled him to be able to track how genetic changes have occurred over time. This demonstrates the fact that ancient DNA analysis has made a massive advancement as more researchers have been able to unravel more information about the history of our inheritance and migration patterns.

The advancement in DNA analysis has allowed us to take a deeper look into the studies of extinct species such as the woolly mammoth and the passenger pigeon. Scientists are using recovered DNA to be able to bring back the woolly mammoths and they are quite certain that they will be able to achieve this goal.



Bringing back woolly mammoths could help reduce the effects of climate change as they trample permafrost (which is a carbon store) which reduces carbon released into the atmosphere. However many people don't want to bring them back as they argue the resources required for DNA analysis should be used to protect the endangered species instead of bringing back the extinct ones. If we have the ability to add genes from old fossil records, then we also had the capability to protect endangered species today.

^*the Asian elephant, a relative of the mammoth*

Finally, another advancement that ancient DNA analysis has enabled is in the field of forensics. For example, there was a wildfire that swept through Hawaii which led to the use of Ancient DNA to identify who died in the fire. In this case, ancient DNA analysis can provide insights and techniques that aided in the fire, helping forensic scientists obtain a better understanding of the event.

In conclusion, ancient DNA analysis stands is a profound advancement in science as it has contributed to the ancient civilisations, extinction and human evolution. This technique has reshaped our understanding of history, breaking the boundaries of scientific expectations to help us connect to the past.

Advancements in the Understanding and Treatment of OCD

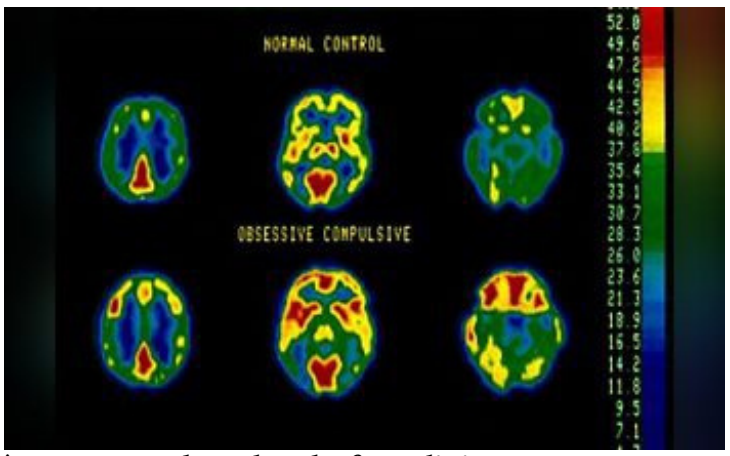
By Sofia Kruse

Obsessive-Compulsive Disorder (OCD) is a complex and often debilitating mental health condition which is characterised by uncontrollable and recurring thoughts (obsessions) and the engagement of repetitive behaviours (compulsions). The study of OCD has evolved significantly over time, along with our understanding of its intricate mechanisms, causes, and treatments.

The history of OCD research can be traced back to ancient civilisations, such as the ancient Egyptians and Greeks, who documented symptoms similar to what we now recognise as OCD. However, these early observations often led to misunderstandings and the belief that the disorder was caused by supernatural or religious experiences.

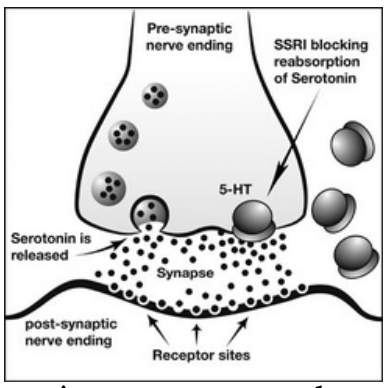
There were significant developments in the understanding of OCD in the 20th century with major influence from Sigmund Freud. Freud introduced the concept of "obsessional neurosis" and proposed that unconscious conflicts could manifest as obsessive thoughts and compulsive behaviours. While his ideas laid the groundwork for psychological exploration, they were not entirely accurate and were untestable.

In the late 20th century, psychologists shifted towards biological explanations for OCD. Neuroimaging studies, such as MRI and PET scans, began to reveal structural and functional differences in the brains of individuals with OCD. These findings pointed towards the involvement of specific brain regions, such as the basal ganglia and the prefrontal cortex.



^*Source: Yale School of Medicine*

In the 1980s and 1990s, researchers explored the role of neurotransmitters, particularly serotonin, in OCD. The development of selective serotonin reuptake inhibitors (SSRIs) as effective treatments for OCD provided compelling evidence of a chemical imbalance in the brain contributing to the disorder. Psychological treatments, such as Cognitive-Behavioural Therapy (CBT), became a pivotal part of OCD management. CBT aimed to help individuals confront and manage their obsessions and compulsions through systematic exposure and response prevention. The effectiveness of CBT in treating OCD was a groundbreaking development.



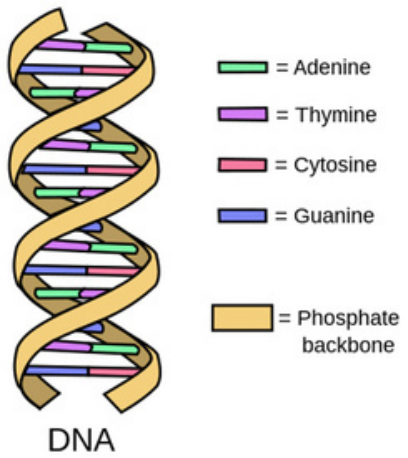
^*How SSRIs work*

Research into the genetic factors contributing to OCD gained momentum in the late 20th century. Family and twin studies indicated a hereditary component, with individuals having a first-degree relative with OCD at increased risk of developing the disorder. This knowledge encouraged further exploration into the genetic basis of OCD. Advancements in neuroimaging, genetics, and neuroscience have continued to shape our understanding of OCD in the 21st century. Studies have uncovered specific genetic variations and neural pathways associated with the disorder, shedding light on its underlying biology.

Currently, a move towards personalised treatment approaches is becoming more prevalent. Researchers are investigating individual differences in the presentation of OCD and tailoring treatments to better suit the unique needs of each patient. While many questions remain, the progress made in understanding the mechanisms, causes, and treatments for OCD has already improved the lives of countless individuals.

Ubiquitin and the Cellular Chamber of Doom

By Dr Dixon

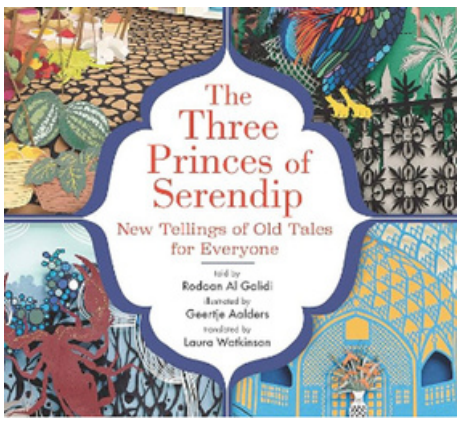


DNA

The 1950s were a particularly exciting time for cellular biology. Hot on the heels of the determination of the structure of DNA in 1953, the first human protein was sequenced by a team led by Frederick Sanger in 1955, for which he was awarded the first of his two Nobel prizes for Chemistry. A human cell contains approximately 100,000 different proteins. Each different protein, coded by genetic information in the nucleus, has a specific shape that allows it to perform its function through complementary associations with different molecules in the cytoplasm and beyond. The elucidation of the genetic code in 1961 finally linked the structure of proteins with the sequence of DNA in the genetic material, and scientists were soon able to begin the process of identifying and cataloguing many of the different proteins found in our cells to gain a better understanding of their function.

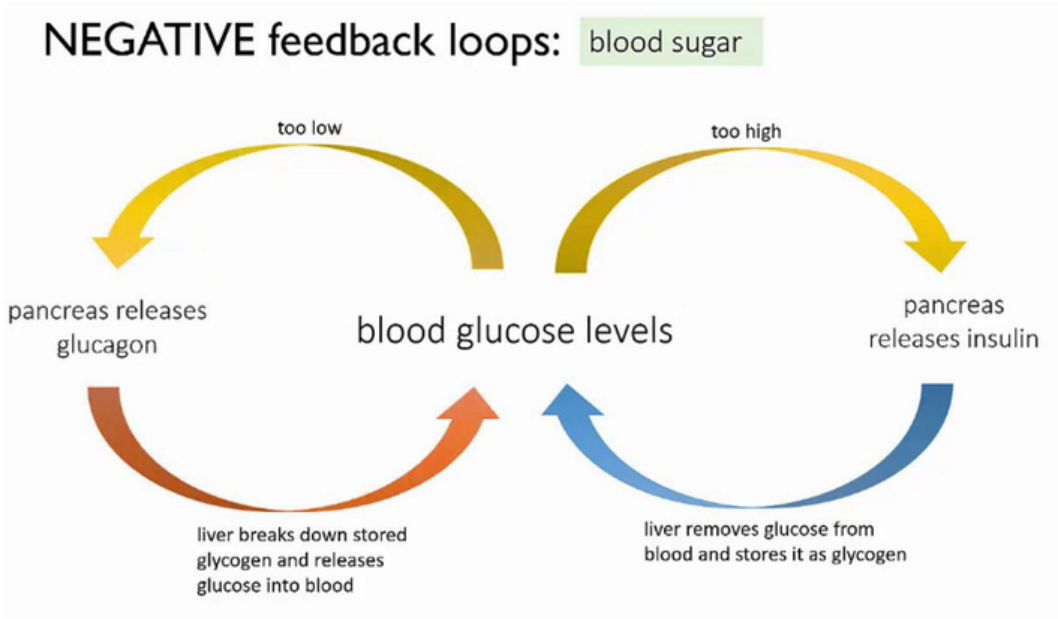
One such protein, discovered in 1975 by Gideon Goldstein in white blood cells, proved particularly enigmatic. Unusually small for a protein, it contained only 75 amino acids – compared to the 574 amino acids in the red blood cell protein haemoglobin – and was expressed (manufactured by ribosomes in the cell using a copy of the gene coding for it called messenger RNA) when white blood cells started to differentiate into either T cells (involved in cellular communication during an immune response) or B cells (which become antibody producing cells). Could this protein be a vital "signal" instructing the cells on what other proteins to express and, therefore, determining the fate of the cell? Initial excitement soon faded when this protein was found not only in differentiating white blood cells, but also in virtually all animal cells. In fact, wider analysis showed that the protein appeared to also be found in plants and fungi. Dubbed "ubiquitin" due to its ubiquity, this common protein proved to be characteristic of all multicellular life but its purpose in these cells remained a mystery. How could a protein found in all cells provide any useful information on their differences?


Ubiquitin

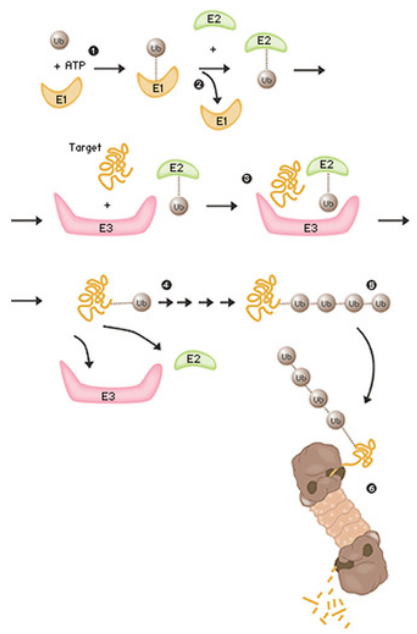


The identification of the utility of ubiquitin required two factors common to many scientific advances: a shift in perspective and serendipity. The perspective shift was about timing. Throughout the 1960s and 1970s it was largely assumed that cells switched on specific genes when they needed a new protein in the cell, and that the proteins then remained in the cell until the death of the cell and its replacement by another. With most cells being short lived, and mitosis being a feature of all multicellular life, this assumption was understandable. The serendipitous event was the combination of a researcher fleeing the Soviet Union in the 1970s (who had continued to investigate ubiquitin after most had decided it was not worth studying) with another team who had discovered a system in cells that appeared to break down proteins. This protein degradation process, requiring cellular energy supply in the form of ATP, appeared to involve combining a mysterious substance in the cell with the protein that was about be destroyed. The mysterious substance turned out to be none other than the protein ubiquitin, and this combination was dubbed "ubiquitinisation". Ubiquitinisation could be seen as the kiss of death for an unwanted protein.

It turns out that quantity of proteins in a cell is carefully controlled through a combination of protein synthesis and protein destruction. Such a concept will be familiar to all scientists as a manifestation of homeostasis through negative feedback. To maintain our blood sugar levels at an ideal level, two competing systems operate, coordinated by the release of hormones by the pancreas. Insulin leads to the removal of glucose from the blood and its storage as glycogen, whilst glucagon leads to the breakdown of glycogen back into glucose again.

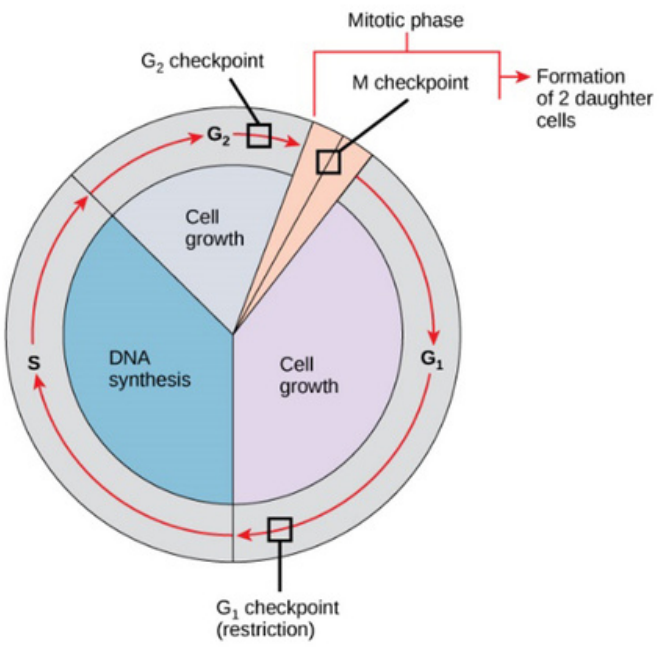


Similarly, the quantities of proteins present in the cell are carefully regulated through switching genes on to make proteins, and then labelling proteins for destruction if their quantity becomes so great. At times when substantial cell modification is needed, more proteins will be broken down than manufactured; by looking at



when ubiquitin was expressed in the cell, rather than where in different types of cell ubiquitin was expressed, its purpose became clear. Ubiquitin was expressed in virtually all cells but only just before proteins needed to be destroyed. Labelling a protein with ubiquitin signals the cell to destroy them in a little known organelle called a proteosome. In awarding the research team the Nobel Prize for Chemistry in 2004, the awarding body described the importance of the Ubiquitin-modulated protein degradation system in controlling cell division, DNA repair, quality control of newly-produced proteins, and important parts of the immune defence.

An example of this is in the development of cervical cancer. In a normally dividing cell in the cervix, a gene called p53 (a tumour suppressor gene) codes for a protein involved in a check point in the cell cycle (G2). The protein pauses cell division until DNA has been checked, and in cells where there are errors in DNA copying, high levels of the p53 gene protein are expressed to stop cell division until either the DNA errors have been corrected, or the cell is destroyed (apoptosis occurs). If a cervical cell is infected by the Human Papilloma Virus, one of the viral genes expresses a protein that causes ubiquitin to be added to the p53 protein, leading to its destruction, release of the checkpoint, and uncontrolled division of the infected cells.



Similar insights into the development of cystic fibrosis and other aspects of the human immune system provide promising avenues for further research.

The Utility of Advancements in Green Hydrogen Technology and its Limitations that Restrict Large Scale Implementation

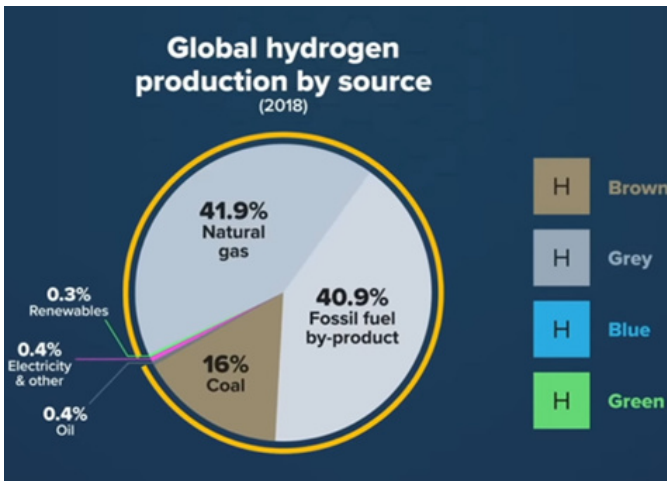
By Juliana Cotton

With the escalating concern surrounding climate change and the environment, it is now essential that as a society we take into consideration the future of cleaner energy technologies that have the potential of sustainably providing fuel and energy for our homes, means of transport and devices in the increasingly populous, modern and industrial world. Despite global efforts to cut down on energy usage, there is undeniably an increasingly high energy demand as a result of growing industries, economies, and domestic technology integration within developing nations and thus, with decarbonisation in mind, it is imperative that we start investing more time and resources into relatively newer, non-fossil fuel/petrochemical reliant methods of fuel production and electricity generation. While there are many interesting sustainable energy resources that are advancing, within this article, I will specifically focus on the advancing technology of green hydrogen.

Hydrogen has the potential to power fuel cell electric vehicles, refine oil, be utilised in the chemical industry's manufacturing of ammonia and fertilisers (as well as producing petroleum in the petrochemical industry) and could even possibly at some point replace natural gas networks that currently provide electricity and heat domestically without producing pollutant emissions.

However, despite being one of the most abundant elements on earth, hydrogen is not found freely in nature. Given its high reactivity, it exists combined with other elements as a compound and requires extraction from those compounds in order to be utilised, which can often be a very energy intensive process and in some cases quite unsustainable.

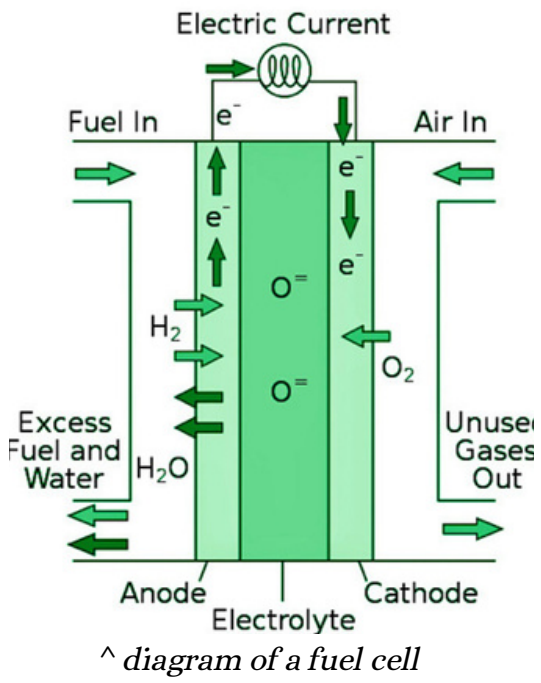
Hydrogen can be categorised into 4 classes, depending on the 'cleanliness' of its production.



Brown hydrogen is produced from gasification (where carbon rich materials are converted into hydrogen) which releases large quantities of CO_2 (carbon dioxide) into the atmosphere.

Grey hydrogen, being the most common form of hydrogen production at the moment, is made from natural gas using steam methane reformation; it similarly emits large volumes of CO_2. Blue hydrogen is also mainly produced from natural gas; however, it incorporates CCS (carbon capture and storage), thus largely reducing its emissions of CO_2. Green hydrogen, however, is produced via electrolysis. This is where an electric current splits a compound (such as H_2O) into its constituent elements. When the electricity used for electrolysis comes from renewable sources, such as wind turbines or solar panels, it can be classified as green hydrogen and is hence carbon neutral!

.

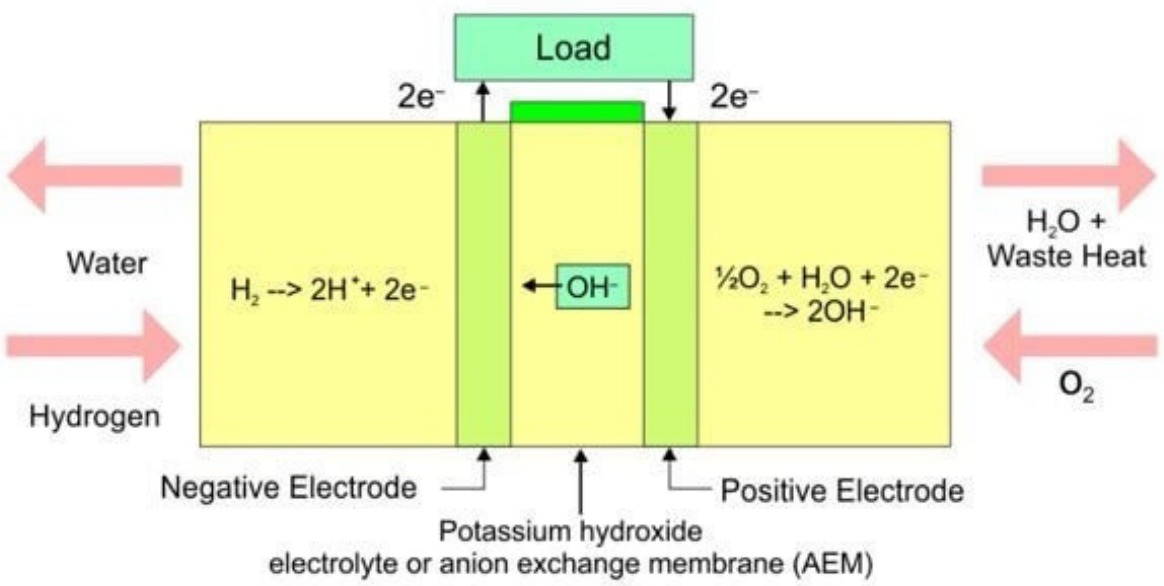


^ *diagram of a fuel cell*

When green hydrogen is used, it can be converted into usable electricity for cars and the general automotive market by a device known as a 'fuel cell'. In essence, when hydrogen is drawn into the cell, it reacts with a catalyst, usually made of platinum or iridium. It is then stripped of its electrons which are then forced to move along an external circuit, thus producing an electric current that can be used by the electric motor to power a car, for example, with its only byproduct being water vapour, instead of CO2 and other pollutants that one may find being emitted for instance by a diesel car.

Although the question remains, in what ways are fuel cell powered cars favourable over regular, battery powered electric cars? The advantages lay mainly in the obvious sustainability, but also in the convenience and practicality. For example, fuel cell cars tend to have much faster refuel times (e.g. 5 minutes versus 45 minutes for an electric car), better energy storage per unit volume and weight as hydrogen is very 'energy dense' (therefore freeing up more space for passengers/storage), greater capacity for 'long-haul trucking', which a lorry with a lithium battery would simply not be able to do without frequently recharging. Nevertheless, there are still unfortunately limitations to the widespread use of hydrogen powered cars.

At the end of the day, hydrogen fuel cell cars are simply unaffordable for many, with the price of them averaging roughly around £50,000, despite cars such as the Toyota Mirai having been in the market since 2014, making them largely inaccessible for the average person. This is likely due to the high costs and scarcity of the PGMs, (platinum group metals) platinum and iridium, that are needed for fuel cells and electrolysers respectively within the process. It is this issue that has prompted more research and development towards AFCs (alkaline fuel cells), which are promising on a cost basis as relatively abundant non-platinum group metals, such as nickel and cobalt are viable catalysts within the AEM (anion exchange membrane) due to their effectiveness in alkaline conditions—however, the drawback does lie in its reduced energy output.



^ *Alkaline fuel cell*

As well as the generally unaffordable price, there is also a lack of sufficient infrastructure to accommodate a potentially increased use of fuel cell vehicles. For example, there are only 814 hydrogen refuelling stations worldwide, the majority of them being in Europe and Asia, presenting the issue that people may be much less incentivised to invest in a hydrogen powered car if they had little to no means to refuel it.

In conclusion, I think that hydrogen is a very promising advancing fuel alternative, offering various advantages both industrially and simply for the owner of a hydrogen fuel cell car; however, I believe that the full potential advancement of this technology cannot be reached without sufficient government policies and investment into research that will make this technology more accessible to a wider scope of people and to scale up its production. Even if it will take time and resources, I think this is greatly important, especially if we want to see significant decarbonisation in the future and a long-term shift away from fossil fuels.

How Women have Advanced our Knowledge of Mathematics

By Dr Samuel

Throughout history, there have been many females who have been trailblazers and advanced our knowledge of Mathematics. Despite this, some have seen Mathematics as a pursuit predominantly for males. One such person who held such a view was Lawrence Summers, who used to be president of Harvard University. In January 2005, at a conference about diversification in Science and Engineering, Summers stated that 'in the special case of science and engineering, there are issues of intrinsic aptitude, particularly of the variability of aptitude, and that those considerations are reinforced by what are in fact lesser factors involving socialization and continuing discrimination'. Unsurprisingly, his theory provoked an enormous backlash, ultimately leading to his resignation in the following year. Further, I intend to prove Summers wrong by highlighting how four famous female mathematicians have advanced our knowledge of Mathematics.

In the Vatican's museums there is a gigantic fresco entitled 'The School of Athens' painted by Raphael. The painting is dedicated to the great Greek figures of thought such as Plato, Euclid, Archimedes, Aristotle, and Socrates plus a blonde figure, half-turned as if to apologise for daring appear to be on the same level as these giants of Philosophy and Mathematics. This figure is Hypatia of Alexandria who happened to be a woman and a mathematician. Theon (Hypatia's father) was a noted Mathematician, and it seems that Hypatia's contribution to her father's work is uncontested. An example of this is how Theon refined and developed the Astrolabe (although he did not invent it), with Hypatia closely linked to this object. Another example is how the comments made by Theon on Ptolemy's Masterpiece were mostly made by Hypatia. Theon himself acknowledged his daughter as being his mathematical superior. Admittedly, it probably helped that Hypatia was the daughter of a famous mathematician, but it seems like that she made the most of the opportunities available to her. Her fame drew many students to Alexandria and she was quite possibly the leading mathematician in her time.

The next great female mathematician I would like to highlight is Maria Gaetana Agnesi (1718 – 1799). Maria was born and died in Milan. If you look at an atlas of Venus, you will discover that a crater is named in her honor – a common tribute paid to great scientists, who are recognised for being the brightest and best and have achieved excellence, not just fame.

^Maria Gaetana Agnesi

By age nine, Maria could speak Latin, Greek and Hebrew as well as four modern languages, which included French by the age of five. This alone demonstrates her phenomenal intellect. She was an all-round prodigy who rose to every philosophical and scientific challenge. Her first unpublished mathematical work was an annotation and commentary on a text written by Marquis de L'Hopital on conic curves (curves which are created by slicing a cone in different ways). Her only published mathematical piece of work can be reduced to a single book which mainly focuses on differential and integral calculus. This single piece of work has stood the test of time for multiple reasons. Firstly, it is a mathematical reference book that is still in print – I cannot think of many books that are still in print after so many years since its initial publication. Secondly, is the transparent language used as well as how it logically and successfully links disparate results. In addition, many have commented how the notation used is so well chosen that it is relatively straightforward for a modern audience to read. The third reason is very profound, particularly given what was happening in the field of mathematics in Europe at the time.

In Europe, the scientific community was divided into two camps, the 'islanders', effectively those who followed the doctrines, explanatory methods and notations as set out by Sir Isaac Newton; and the 'continentals' who followed the teachings of Leibniz. The modern-day equivalent would be probably something like the rivalry between Arsenal and Manchester United, particularly when Arsene Wenger and Sir Alex Ferguson were their respective managers. Maria manged to do what many perceived the near impossible and united the two equivalent intellectual viewpoints by taking the best from each. Further, Maria stresses how differentiation and integration are reciprocals of each other – a very modern viewpoint.

I cannot write an article about famous female mathematicians, without a reference to The Simpsons and the episode 'Girls Just Want to Have Sums', particularly as it mirrors the life of the next female mathematician I want to focus on, Sophie Germain (1776 – 1831). In the afore mentioned of The Simpsons episode, Lisa decides to dress as a boy to study what is perceived to be 'real maths'. Towards the end of the episode, Bart declares "the only reason Lisa won is because she learned to think like a boy; I turned her into a burping, farting bullying math machine". At the climax of the episode Lisa states, 'I guess the real reason we don't see many women in math and science is…", at which point she is interrupted by Martin playing the flute. This is because, according to Simon Singh, the writers did not want to end up in 'Skinner like trouble'. Quite possibly because they may have suffered the same fate as Lawrence Summers, the now former president of Harvard University.

^Sophie Germain

Just as Lisa adopted a male persona, Sophie Germain adopted a male persona by writing under the pseudonym Monsieur LeBlanc. Although Sophie could not attend the newly opened Ecole Polytechnique in Paris (which was her desire), the prestigious institution had made the lecture notes publicly available. The issue was that this was intended for men only. Hence, by adopting a male persona, she gained access to these notes, and submitted her insightful observations to none other than Joseph-Louis Lagrange, one of the world's most respected mathematicians, who also happened to be a member of the Ecole Polytechnique. He was so impressed by the observations submitted to him he demanded to meet Monsieur LeBlanc. This put Sophie in an awkward position as she now had to give up her adopted male persona (just like Lisa) and reveal her true identity. Lagrange was pleasantly surprised and allowed Sophie to continue with her studies. After corresponding in a similar way with another famous mathematician, Carl Friedrich Gauss, who was also astonished by Sophie's intellect and wrote 'then without doubt she must have the noblest courage, quite extraordinary talents, and superior genius.'

Sophie Germain's most famous contribution to mathematics was in relation to proving Fermat's Last Theorem. Despite the fact that Sophie was unable to formulate a complete proof, she made more progress than anyone of her generation. This led to the Institut de France to awarding her a medal for her achievements.

The last mathematician I want to highlight is Grace Murray Hopper (1906 – 1992). In 1983, she was appointed a Rear Admiral of the US Navy at the age of 77. She is also the only mathematician to have a ship named in her honour, the destroyer USS Hopper. Under the supervision of a famous mathematician, Oystein Ore, she obtained her doctorate in mathematics from Yale University, quite an achievement given that she was the first woman to do so.

^Grace Murray Hopper

After the second world war, computers were being used more for civilian uses rather than military applications that were useful during the war such as code breaking. Its development was continuing at a rapid pace and unstoppable. Grace made a considerable contribution to developing computers for civilian use and in 1950, successfully predicted that software would eventually become more expensive than computers – time has proved her right. Further, Grace used her knowledge of mathematics (she was able to fluently count in base-8) and computers to develop a high-level entry computer language called COBOL (Common Business Oriented Language). The language was such a reliable and proven language, that it was used for over half a century. It has even made its way into Hollywood; the Terminator robot played by Arnold Schwarznegger 'speaks' COBOL.

I started out by wanting to prove that Lawrence Summers was wrong, and how women have the same potential as men to advance our knowledge of mathematics. Even though I have only highlighted three women (and there are many others I could have written about, such as Florence Nightingale, Mary Fairfax Sommerville, Sofia Kovalevskaya, Julia Bowman Robinson), I have hopefully convinced you that Lawrence Summer's theory is incorrect and that women do have the same potential as men to advance our knowledge of mathematics.

How has Veterinary Medicine advanced over the years?

By Grace Blackhurst

Veterinary medicine can be traced back to 3000BC, with a man named Urlugaledinna who was well-known for being an “expert in healing animals”. However, the modern foundation of the veterinary medicine took shape in 1761, when Claude Bourgelat opened the first veterinary school in Lyon, which primarily focused on equine studies, due to the significant role horses had in the army, agriculture and transport at the time.

Development of veterinary medicine in Britain began in 1785 when the ‘Odiham Agricultural Society’ held a meeting that established the opening of the ‘London Veterinary College’ in 1791, which also largely focused on equine and other farm animals. The landscape of veterinary medicine has experienced a significant switch from its initial emphasis on horses and livestock to a wider spectrum of animals. Currently, there are nine universities in England and Scotland that offer veterinary degrees – this is after vet schools were first integrated into the university system in 1946.

Veterinary medicine has developed beyond recognition since then; this is starkly evident in diagnostic advancements. Cutting-edge imaging techniques such as CT scans, digital radiography and ultrasounds have revolutionised veterinary diagnostics. CT scans were first created in 1972 by Godfrey Hounsfield and Dr Allan Cormack, and they allow vets to see an animal’s brain, spine and bones aiding in the diagnosis of cancers and various spinal cord injuries. Additionally, digital radiography can reveal fractures, cancers and arthritis within the body, while ultrasounds can view the heart, liver, kidney and reproductive organs.

Furthermore, there has been significant advancement within molecular diagnosis. This is where an animal’s genes are assessed, using PCR (polymerase chain reaction) and NGS (next-generation sequencing) to analyse DNA and RNA to detect genetic defects and infectious diseases.

For example, PCR is used to detect parvovirus, a highly contagious virus targeting dogs and NGS can uncover canine influenza virus, an infectious respiratory disease that infects dogs and cats, by sequencing an organism’s entire genome.

The integration of technology into veterinary medicine has further transformed the practice. The development of internet remote consultations and tele-health apps have become increasingly common. For example, the ‘Joii Pet Care’ app was launched in 2019 and was developed by Vet-AI. This app was particularly useful throughout the COVID-19 pandemic, as when pet owners struggled to access in-person vet care, online consultations were their best option. Technological developments have allowed veterinary nurses and surgeons to store records electronically, ensuring secure storage and easy organisation of files.

The rise of robotics has also allowed for growing possibilities of use within veterinary medicine. Surgical robots are being used more often as they offer precision and cause minimal scarring. As well as this, robotic rehabilitation can be used to monitor an animal’s recovery by analysing their movement. Moreover, developments in AI have allowed for the use of decision support systems within clinics which give case-specific counsel, recent research and evidence-based advice to a vet on how best to help an animal.

Overall, vet medicine has advanced in so many ways due to the development of new technology, which has allowed for veterinary surgeons and nurses to access as much advice and research as possible from around the globe and via AI.

The veterinary world has changed beyond measure since the founding fathers created the profession in the 18th century, with huge developments in diagnostic machinery.

The pace of change is accelerating; the next few years promise to bring more exciting developments.

The Pros & Cons of the Enhancements of Gene Editing Technology - CRISPR

By Lucy Greenhalgh

CRISPR was devised in 2012 by the three co-inventors Jennifer Dounda, Emmanuelle Charpentier and Feng Zang. The mechanism for it and the name were given by Francis Mojica of the University of Alicante in Spain.

CRISPR stands for Clustered Regularly Interspaced Short Palindromic Repeats. Originally, it was widely found in prokaryotic cells (such as bacteria) and formed the hallmark of the bacterial immune system. It works by exploiting a natural DNA-snipping enzyme in bacteria called Cas9, which then targets and edits particular genes. Dounda, Charpentier and Zang transformed this into gene-editing technology by designing customised CRISPR DNA to target genes of interest and then, using the enzyme Cas' variants (such as Cas3), made desired modifications to the bound DNA.

Today, and in the future with continued development, it hopes to enable geneticists and medical researchers to edit parts of the genome (the complete set of genes or genetic material present in a cell or organism) by removing, adding or altering parts of the DNA sequence. But what are the promises of this potentially transformative technology? What are the controversies that may arise if CRISPR technology continues to be enhanced?

Pros of CRISPR

In modern medicine, CRISPR technology promises to solve three major problems:

1) Genetic diseases, such as cystic fibrosis and Sickle cell anaemia, are caused by a single gene mutation. As CRISPR is a gene editing technology, it could cure these diseases by repairing the single mutated gene. This clearly would be not only life-changing but also lifesaving for so many individuals who suffer from these genetic conditions.

2) CRISPR can improve the drug development process. Research in medicine is often troubled by poor translation of promising findings into successful clinical trials. For example, analyses of clinical trial data from 2010 to 2017 show that 90% of clinical drug development efforts failed. The major reason for this is the lack of clinical efficacy. CRISPR could improve this by directly up-regulating (increasing the cell's response to the molecule) or down-regulating (reducing the cell's response to the molecule) genes. This will determine which products of genes are responsible for disease and therefore can allow researchers to identify more effective drug targets leading to faster drug discovery.

This means that medicine will get to patients quicker, improves how well the drugs work and minimises patient risk.

3) Lastly, one of the biggest concerns facing patients is antibiotic resistance. This is when bacteria develop the ability to defeat the drugs designed to kill them. CRISPR can be used to discover new antibiotic targets which develop resistance less often.

Cons of CRISPR

Despite the benefits of CRISPR, it is not perfect and therefore also brings to the table some controversies:

1) Safety is a major concern when discussing gene editing technology. This is because there is a risk for random, off-target mutations to occur which may result in unwanted side effects such as accidental alteration of a tumour suppressor gene may result in cancer.

2) CRISPR, whilst bringing the potential for patients, also brings forth severe ethical and moral concerns, especially regarding justice in society. This could be seen if people use CRISPR to enhance normal human traits, such as parents wanting a child to be taller or have a specific eye/hair colour. This causes conversations about the importance of equity and diversity in society; the phrase 'you get what you get' may come to mind.

In conclusion, medical researchers are excited over the future advancements of gene editing technology and the promises they bring to the world stage, such as no more fear of prescribing antibiotics to treat infections due to the potential of resistance. However, it must be noted that as we learn of new, and powerful, ways to control the natural world and our evolution, we must learn to wield this knowledge with reason, responsibility and a steady hand.

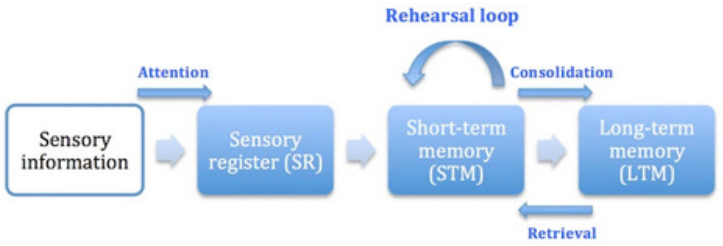
How has Psychology and Cognitive Research furthered the Science of Learning

By Matilda Stoakes Ballard

Cognitive psychology is the scientific study of internal mental processes, such as memory, perception, problem solving and thinking. It is used, alongside research on education, in the science of learning to understand the processes through which we learn whilst connecting it to practical implications for teaching. Since cognitive psychology's emergence in the 1950s, it has played a crucial role in helping us gain an in depth understanding of mental events that contribute to our daily existence and has had many useful applications. It is an ever-growing area that continues to enrich our understanding of many mental influences.

Memory is involved in processing vast amounts of information which can take many forms. The cognitive learning theory, and much of psychology, uses an information-processing model to explain how information flows through the cognitive system in stages. In a certain type of model called the computer-model, mental processes are metaphorically compared to the actions of a computer, concerned in the way we "encode," "store" and "output" information. When information is originally transmitted from a sensory input, it must be encoded into a form that the system can cope with so it can be stored. The three main ways in which information can be changed are visually (through pictures), acoustically (through sounds) and semantically (through meaning). Memory storage concerns the nature of memory store, including the duration, capacity and quality. The way in which we store memory affects the way we retrieve it, for example, short-term memory can only store information for a short amount of time (0-30 seconds), whereas long-term memory can last a lifetime. Long-term memory is stored and more successfully retrieved by association and organisation (e.g. alphabetically, by size, or by time). To learn, individuals must transform information from working memory (where it is consciously processed) to long-term memory (where it can be stored and later retrieved).

Cognitive neuroscience studies the influence of brain structures on mental processes and is used to discover which cognitive functions are linked to specific areas of the brain.



^The Multi-Store Model of Memory

This is done using brain imaging techniques such as fMRI and PET scans. Cognitive neuroscientists study many different aspects of human cognition, including the neural processes underlying memory, attention, perception and awareness. It is through this research that scientists have found that the hippocampus is responsible for retrieving and storing memory, and that the prefrontal cortex is activated during learning. The prefrontal cortex is an important site for working memory function (processing information), thinking, and is involved in the formation of memories. Memory is the reactivation of a specific group of neurons, formed from persistent changes in the strength of connections between neurons. Remembering is not passive but rather an active process in which information is retrieved and practice is essential to learning new facts.

Through scientific cognitive research, psychologists and educators have developed effective strategies to enhance learning and studying. For example, retrieval practice; the act of retrieving knowledge from memory strengthens connection as neurons in the brain grow, making it easier to recall information. Active learning is also a helpful method because it stimulates a variety of areas in the brain and promotes memory: there are numerous ways to engage in active learning, such as teaching someone else or using the 'blurting' method. The way in which you space your retrieval is also important; research has shown that spaced learning can be twice as effective as regular revision because it helps encode information into long-term knowledge. Overall, cognitive psychology research has fuelled the science of learning by explaining the ways in which we process information which has helped us develop methods to improve the way in which we learn.

Was the steam engine an 'advancement'? An analysis of scientific and engineering 'advancements'

By Imi Bell

What is an advancement?

'Advancement' is defined in the Oxford dictionary as 'the process of helping something/somebody to make progress or succeed', and in the Cambridge dictionary it is defined as the 'development or improvement of something'. This shows us that 'advancement' does not always mean the progress made in new technological and scientific fields, or feats of engineering, it merely means that it is something which creates progress or improvement. This concept is very applicable in the time period we are currently unofficially in: The Anthropocene Epoch, where we have learnt that previous scientific 'advancements' (such as the steam engine) or the industrial revolution and the plethora of technological advancements and 'steps forward' that it brought with it (such as the production of fossil fuels) were in fact not advancing the planet but simply leaving it in disrepair. This is what raises the questions such as: are advancements advancements? Is there a way of combining scientific and technological advancements with ethical concerns to prevent this misuse occurring in the first place? To assess this concept, I have used an example of the 'advancements' in marine transport technology.

However, these questions are applicable to almost every part of scientific advancement. For example, were the scientific advancements made in chemistry and physics when creating the atomic bomb truly progressing anything if it just created destruction in the hands of humans? Were the technological advancements leading to the internet, social media, and artificial intelligence truly allowing humanity to succeed, or have they backfired brutally upon us?

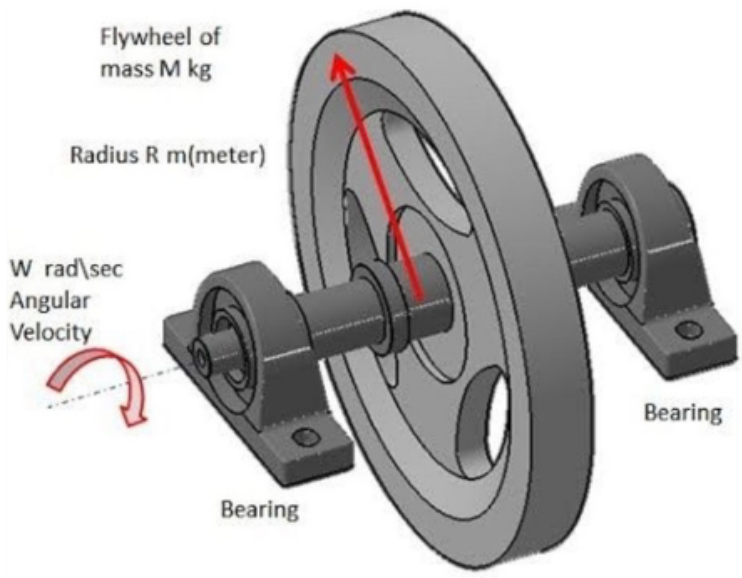
How does the Steam Engine Work? – A brief history & scientific explanation

Sailors of the 'sail ship time' were very scientific people. They had to learn how to work with the natural elements like weather, climate, tides and current, implementing rules of physics, chemistry, and biology into their everyday lives. Merchant sailing ship captains of those days would often have huge amounts of knowledge and interest in the wonders of the deep. They would examine and classify the specimens of the sea, not unlike how scientists do nowadays.

The first commercial steamboat was the North River Steamboat, built in 1807, which was followed by a huge rise in popularity of steam engines used in marine transport. Most sailors and captains of sailing ships then left the industry as steam engines took over, regarding it as an insult to their science of sailing, and a step towards working directly against the ocean, rather than with it. Steam engines eventually evolved into steam turbines, which are still in wide usage today, as well as the use of diesel fuel, nuclear power, and even electrical propulsion. However, the steam engine was the first step in advancing marine transport from the many years of sails and oars as use of marine propulsion.

^the North River Steamboat

There are multiple different types of steam engine, however the basic science and engineering of each one is based on the same concepts. When water is heated and boils, it generates steam, which is typically done with a boiler fuelled by coal, oil, or gas (the burning of which emits greenhouse gases). While it could use solar or nuclear power, this practise was not possible in the times when steam engines were in consistent usage. This steam then travels through a carefully controlled intake valve into a cylinder containing a movable piston. This causes a process called the power stroke, where the high-pressure steam exerts a force on the piston, transferring into kinetic energy and causing it to move down the cylinder. This power stroke is followed by the exhaust stroke, where the exhaust valve allows steam to exit the cylinder while the piston moves back to the start of the cylinder, driven by a mechanism. These mechanisms vary from a flywheel to other separate pieces of equipment. A flywheel is a heavy wheel attached to the piston to smooth out delivery of power from a motor to a machine, as well as store excess energy. This all creates mechanical power from the reciprocating piston motion, which drives machinery such as the locomotive wheels seen in steam ships. In some types of steam engine, there would be a condenser used to transfer steam from the exhaust valve back into water to be reused.



However, while these steam engines are widely seen as a revolutionary advancement in technology and engineering, how far can they be seen as advancements? They set us down a path of transport becoming increasingly damaging to the environment through the use of fossil fuels to drive machinery. As a result, we are seeing a planet, that is not advancing, but declining in many aspects, such as biodiversity.

It is important to note, however, that these scientific advancements are definitely ‘advancements.’ This is because science, and therefore scientific discoveries, are not inherently good or bad. The meaning of progress in science is simply discovering more about how things work. It is how these scientific advancements are applied that have arguably taken us so far away from advancing and left us at the end of a metaphorical cul-de-sac. There is room for debate then, that the ‘experiment’ of implementing such innovations like the steam engine has been a scientific advancement in itself, as it has taught us more about how things like the steam engine have affected the world, which is a scientific advancement in itself. It is the usage of scientific and engineering advancements in human hands that turns them into dubious examples of progress and success.

The Advancement of Nanotechnology in Forensic Science

By Eloise Milligan

What is nanotechnology?

Nanotechnology is the branch of science that researches the manipulation of matter at a nanometre scale, 1-100nm. At this scale, materials can exhibit different properties due to a higher surface area to volume ratio, which gives them enhanced properties such as higher durability and conductivity. Nanotechnology can be applied to a variety of fields, such as engineering, medicine and forensic science.

How does nanotechnology link to forensic science?

A new area of forensic science called 'nano-forensics' is being used to develop technologies that can help with crime scene investigation, as well as determining the presence of biological agents. Nanotechnology has a role in the following:

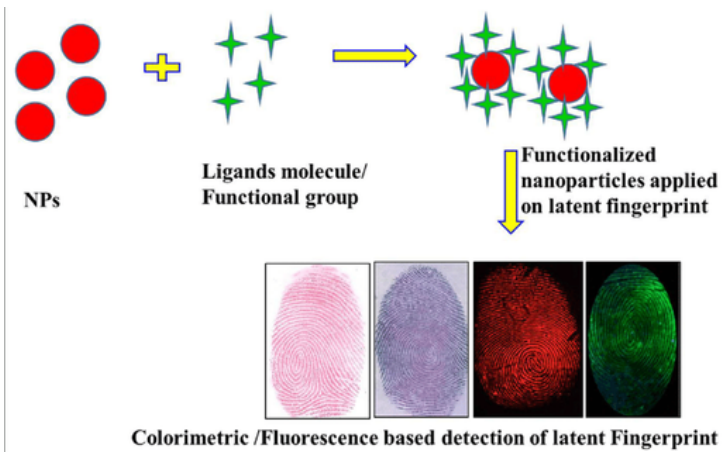
• Fingerprint visualisation

There are three kinds of fingerprints that are used to identify a person in a crime scene: latent, patent and plastic. Latent fingerprints, however, are the only type that require nanotechnology to analyse them, as they are not visible to the naked human eye. The pads of your fingers contain pores which are attached to sweat glands under the skin; this means that the print that is left behind is just an outline of sweat from your finger pores. Fingerprint powders are generally used in crime scenes to reveal prints- the powders stick to the sweat residue left by the finger to make it visible. However, new methods of nanotechnology have been introduced that have made it more accurate to analyse fingerprints, also enabling scientists to discover further details. Gold nanoparticles, for example, have been used by researchers to identify amino acids on non-porous surfaces.

• Explosive detection

In recent years, hidden explosives have become more commonly used in terrorist activities. These explosives are only detectable by the very small quantities of gas that they give off which are difficult to detect. There are already systems and technologies that can detect compounds in the gas phase, although they are expensive, inconveniently bulky and have a limited sensitivity. The advancing research into nanotechnology has attracted interest in this field as nano-enhanced sensors can be added to pre-existing technologies (such as bomb disposal robots) to enable them to identify very small amounts of airborne chemicals. Nano-sized sensors would react to the absorption of specific molecules, such as explosives, and then would change the electrical signal slightly to produce an overall measurement. This measurement would then be interpreted to determine the presence of traces of explosives, which would alert the user of the explosive's presence and magnitude.

Overall, nanotechnology has and will further advance the field of forensic science. In the future, nanotechnology will be used as an innovative tool in the various areas of forensic science to help identify dangerous toxins in the atmosphere as well as fingerprint identification. These developing technologies will be helpful in supporting forensic and security measures in crime investigations.



^Latent fingerprint developed on various nonporous/semi-porous surfaces using functionalised nanoparticles

How beneficial is the advancement of crypto currency?

By Darcey Taylor

Since being introduced to the world in 2013, there are now 420 million global crypto users and this number is rapidly increasing. With our world becoming ever more reliant on technology, more people are switching from cash to this digital form of currency. Large companies such as Tesla are jumping on this new technology with Elon Musk investing $1.5 billion into bitcoin in February 2021. This new form of money seems to be the future when you hear about its lightning speed transaction times or the very low levels of criminal activity. However, is this actually beneficial to the general population and the economy?

What is cryptocurrency?

Cryptocurrency is a form of digital currency that uses block chain technology to keep track of payments meaning that it's traceable. It is estimated there are 23,000 forms of cryptocurrency. Bitcoin is the most famous and was the first to be invented. Every purchase is recorded in a block which contains transaction data such as who was paid by who, how much was transferred and a hash of the previous block in the sequence. If something in the block changes, the hash of that block has to change as well. Currency exchange is a common option for people to choose when investing in cryptocurrencies, especially beginners because they are simple and hassle-free for users. They allow customers to trade cryptocurrencies or digital currencies for other assets such as fiat money or other digital currencies. Exchanges also enable investors to buy, sell, and hold cryptocurrency and allow users to transfer crypto to their online wallets for safekeeping. However, there are other ways to purchase or invest crypto such as using a crypto wallet or crypto funds.

What are the advantages?

There are a multitude of advantages when using cryptocurrency. Many believe the fact that crypto is decentralised is one of the greatest advantages. This means that there is no 3rd party interference so it is not controlled by any government or central authority. Fewer people are vulnerable to malicious behaviour which creates improved online safety. Users gain more power as they do not need to trust anyone which promotes faster and smoother transactions. Another key benefit is how easy it is to prevent hacking or robbing of the user's crypto which could be the future for open and traceable transactions. Everyone who is part of the network has a ledger which is one enormous spreadsheet which tracks and records all of the purchases and exchanges made with crypto. It's constantly updating!

In order to take a user's money, a robber would have to tamper with that specific block and every single block after that in the sequence: each block's hash has to match up with the next block's hash. As a result of this, the hacker could potentially have to change thousands of blocks and on millions of computers. At least half of the ledgers in the network have to have those hacked blocks for the system to approve it which makes it near impossible for hacking to take place. In fact, only 0.34% of crypto exchanges are criminal compared to the 5% criminal cash exchanges. Payments can also happen instantly with either no or very low transaction fees. However, this does not mean that cryptocurrencies do not have their risks and downfalls as well.

Some may believe that the main way we are making transactions at the moment through normal cash and banks is completely sufficient especially with the disadvantages of cryptocurrencies. Others see this as the future. The disadvantages do entail how volatile the market is for cryptocurrencies. It can change in a matter of minutes – one of the reasons being no one actually knows what these currencies should actually be worth. For example, when an article from a popular newspaper is published that paints crypto in a positive light the value suddenly skyrockets. Or on the other hand, when Elon musk posted a negative tweet about crypto on his X account, the value of crypto decreased drastically. This is why so many people are reluctant to invest in crypto because you could risk losing all of your money. There are also negative environmental factors linked to mining cryptocurrencies. This is when someone has a copy of the ledger as well as having a computer set up to process all of the transactions happening using the certain cryptocurrencies that their network is on. In return, as compensation, users are given cryptocurrencies.

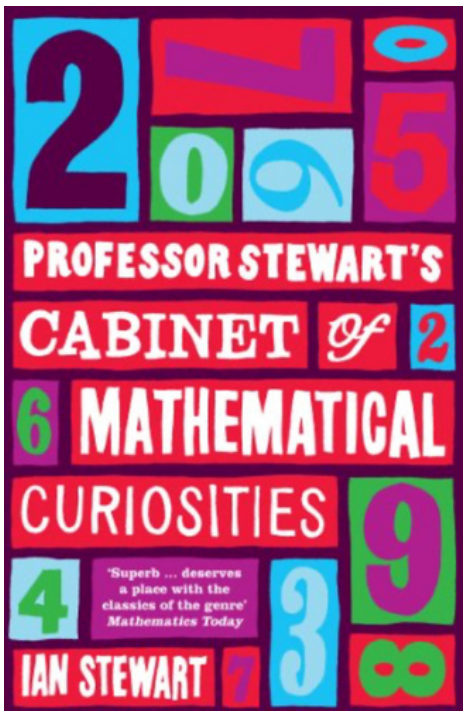
In 2021, there were one million bitcoin miners with many of these using multiple computers to mine. This requires huge amounts of electricity and energy use that has a negative environmental impact. As well as this, it is costly to mine bitcoin due to the computer and electricity costs so some people could actually risk losing money when mining crypto. Many companies do not actually accept this as a form of currency which is a factor to take into account if you are considering investing yourself. At present it does not seem feasible to switch fully from cash to cryptocurrencies due to the lack of development in poorer demographic countries. I believe that cryptocurrencies will take time to stabilise in the market to the point where there are multitudes of beneficial reasons to switch currencies. For now, I think I might just stick to Apple Pay!

Features section

Maths reviews

Maths Reviews: 'The Cabinet of Mathematical Curiosities'

By Dr Samuel



As the holiday season approaches, I thought I would review a book that contains lots of games, puzzles, stories and factoids about Mathematics that would demonstrate why it is an endlessly interesting and fascinating subject. 'The Cabinet of Mathematical Curiosities' is one of those books that you do not have to read from front to back to follow the path or story that the author has pre-determined, but a book that you can dip into now and again, perfect for the busy holiday season ahead. There is a Curiosity in this book for everyone to engage with.

Professor Stewart started keeping notebooks from the age of fourteen in which he recorded all manner of things that he found interesting. The set of notebooks grew to a total of six, and overspilled into a filing cabinet, mainly due to the invention of the photocopier. In his introduction, the author points out that Mathematics is not simply the sum of everything that is studied at school. There are various aspects that we do not get to explore in school, and much of it is fun and interesting, which is a viewpoint that as a fellow mathematician, I happen to whole heartedly agree with.

Throughout the book, amongst the various puzzles and factoids, are short essays, in which the author has adopted an informal and non-technical approach to explore some of the more complex aspects of Mathematics, such as the Four-colour problem, Chaos Theory and Fractals. The book also contains, in the words of the author, 'some shorter snappy sections' that explore various discoveries such as π, prime numbers and Pythagoras' theorem. In the book, anecdotes about famous mathematicians are also included, as well as their 'endearing foibles', which not only gives the reader a historical perspective about the subject but also weaves a sense of humour into the book.

On some occasions, when attempting to solve a problem, a whole new area of Mathematics is born. These occasions are rare, and probably the most famous problem is The Bridges of Konigsberg problem. In Konigsberg there are two islands connected by seven bridges. This gave rise to the following conundrum:

Can you find a path such that each of the seven bridges is crossed exactly once?

This was a question that Leonard Euler set out to solve in 1735, and this led to the birth of graph theory. I will leave you to read the book to discover if Euler managed to prove if a solution to this problem exists.

One of my favourite pieces in this book is the 'Six Degrees of Separation'. In 1967, Stanley Milgram prepared 160 letters with the name of his stockbroker on the envelope, but none of the envelopes had addresses on them. He 'lost' the letters so that random members of the public could find them, and hopefully send them on. When the letters had arrived at the stockbroker's office, they had done so in at most six steps. This led Milgram to the idea that everyone on the planet is connected by a maximum of five intermediaries, which gives the six degrees of separation. The concept behind this is that there are some people who are incredibly well connected that form the connections to allow smaller networks to be linked together. There is a similar idea linking famous actors/actresses to Kevin Bacon as he has been in a large number of films. Anyone who has been in a film with Kevin Bacon has a Bacon number of 1. An actor/actress with a Bacon number of 2 would have been in a film with an actor/actress who has been in a film with Kevin Bacon, and so on (see oracleofbacon.org for more information). The challenge here is to see if you can break the six degrees of separation, and again, I will leave it to you to read the book to discover more about the six degrees of separation.

During your holidays, find time to dip into this wonderful book to widen your Mathematical knowledge - you may find some amazing new 'trick' or factoids to amaze and astound your family and friends.

Broody Technicoloured dinosaurs and bird spyware
An Exclusive In-depth Interview with Professor John Quinn 2.0

By Sora Kamide

Professor Quinn is an ornithologist (an expert on birds), sometimes describing himself as a behavioural ecologist and looks at multiple areas including genetics and the microbiome! He is a lecturer at University College Cork, school of Biological, Earth and Environmental Sciences.

Sora: Have there been advancements in our understanding of the evolution of birds?

Professor Quinn: There has been an increasing amount of focus on the colour of dinosaurs. Well, how can you possibly study the colour in fossils?

Colour is caused by a couple different things in birds and animals in general, one of them being these little organelles called melanosomes. These organelles have a very specific shape and it turns out that you can actually see them in fossils. The shape of them tells you something about their likely colour.

The second thing they can do is analyse the different pigments given that they have specific chemical make ups. Some of this is preserved in fossils, so you can actually see what sort of chemical make-up is in the skin of these fossils and therefore infer something about their colour.

So, we are beginning to have a good understanding of the colour of many of these species. Their colours aren't as complex as they are in modern birds - modern bird colours are much more sophisticated. It's caused not just by these pigments but by diffraction of light. The particular chemical makeup of bird feathers means that you get this diffraction of light and sometimes you can have multiple layers and therefore you get multiple types of diffraction and that makes the colours look iridescent. So those things we don't think were in the early dinosaurs. We now know that probably most of the colours were pigments.

Another discovery is to do with the behaviour of these birds. There was a famous fossil finding many years ago, in 1923, of a species of therapod dinosaurs called oviraptor - ‘ovi’ meaning egg and ‘raptor’ meaning to steal. The oviraptor was thought to feed on eggs since the fossils showed the dinosaur on top of eggs. But now we think that actually that the oviraptor could have been incubating the eggs and taking care of the nest.

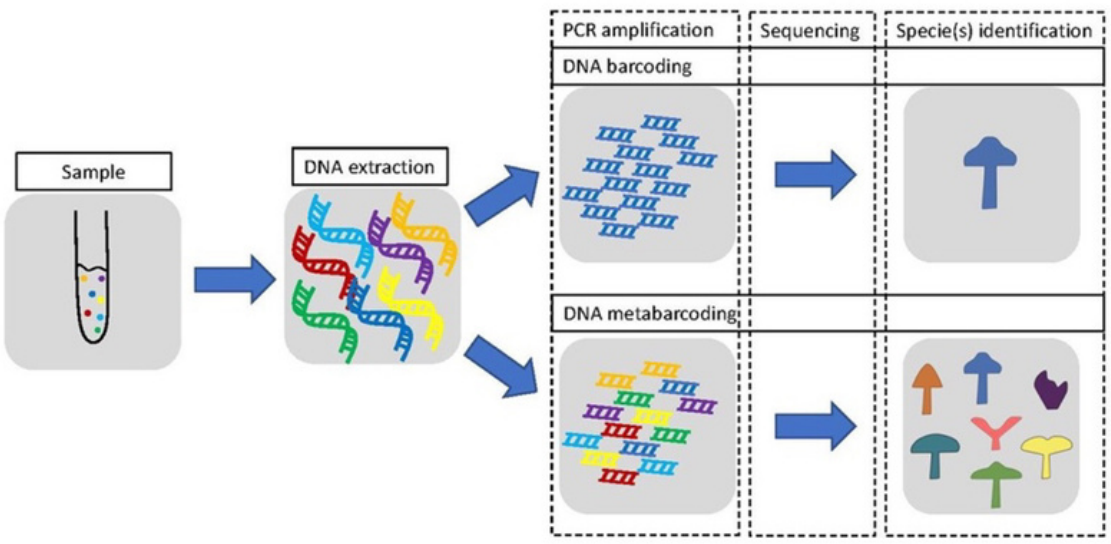
That is surprising because we didn't think dinosaurs incubated eggs at all but there's increasing evidence from some of these early tetrapods that they may have.

The reason they couldn't just sit on the eggs like birds was because they were too heavy. So what they think was that initially they were just protecting them by covering them but not sitting on them and then they found that maybe they were partially sitting on them but with the eggs possibly buried or supported by sand so they didn't get the full weight of the dinosaur, until eventually as the dinosaurs became lighter and lighter to begin incubating.
Whether that has actually happened is not entirely clear but again chemical analysis of fossils have suggested that it might have done. This is to do with isotopes of oxygen. The specific ratio of those isotopes varies depending on what temperature that eggs are at during the development. This has been examined and the ratio suggested that the temperature was quite high - around 40-45 degrees Celsius which suggested the eggs would have been incubated.

Sora: Have there been any advancements in bird research involving the use of DNA?

Professor Quinn: I have been using DNA in the context of the diet.

In birds of prey, it is very easy to see what they are eating but in smaller birds it is rather tricky. Cameras can be put in the nest, but generally you can't identify the species of their prey. So now, we collect the faeces samples of the birds and carry out DNA metabarcoding.



DNA metabarcoding is where we sequence all the DNA we can find in the faeces and compare them to the sequences of all known species of invertebrates that have been sequenced. That way you can identify what kind of species the birds are bringing back to the nest. For example, in our research of the great tit, we have found almost 200 species of invertebrates!

We also use DNA to discover more about the gut and microbiome.

We found in our study system that there were certain species of microbes that seem to be really important for the development of chicks in the nest. Those which have a good population of these microbes seem to put on more weight. We do not fully know the mechanisms, but we know certain species of microbes have important functions, so if you identify the microbe, we can often tell by looking at the genes what the dominant genes of those microbes do. It might be helping to process proteins, interact with their immune system and so on, since all the microbes in our gut carry out a function.

We isolated some of these microbes from birds and cultured them ourselves to feed back to the birds as a probiotic. We put worms doused in the cultured probiotic outside one nest box and also worms without the probiotic outside another nest box for the parents to feed their chick. From this, we saw the nest which fed on the worms with the probiotic had gained more weight to benefit the condition of the chicks. Finding such prey with the right microbe is all down to the environment - if you get a healthy environment, that seems to alter your microbiome

Another way DNA has been used is to identify the parentage of chicks.
Like swans, many garden birds have a partner and that partner is with them for life - likewise for robins. For a long time, we have assumed that all the eggs in the nest all shared the same father. But it turns out that a lot of the eggs are from different fathers!

Females are mating with multiple males to try and bring diversity into their clutch. A female lays one egg every day and each day it is from different partners. There is competition between males for females, even in the nest that you think the male has control over!
This is one of the reasons why you often see males being very elaborate - they tend to be more colourful since females are very selective of who they reproduce with.

Sora: Have there been any new advancements in use of technology to help research of birds?

Professor Quinn: We used to track birds and animals in general by using tags that we would visually see to re-trap the animal and read the number.

Now we use GPS technology and satellites to work out where animals are going. But in the last ten years these tags have become incredibly small. We can even put tags on bees! Such tags do have limited range as they use radio frequencies but the GPS tags using satellite range is not a problem. No matter how far the animal goes in a year, if you can re-trap the animal again, you can see where it has been in the past 12 months. Scientists at Oxford showed that seabirds in Wales go down to the south coast of Argentina in the winter and travel in almost a figure of eight around the Atlantic.

We study very small seabirds which only weigh around 30g and in such cases, the tags must be kept at 1g as they must be less than 3-4% of their body weight to not impact the bird. However, a big limiting factor is the battery size.

From these advancements in tracking birds, we have found when finding food, storm petrels, despite only being the size of swallows, fly up to 500 km.

Shearwaters (which are related to albatross) can do round trips up to 3000 km to find one meal for their chicks.

Albatrosses can do round trips up to 10 to 14 thousand km to find food.

Sora: Has there been advancements in understanding how birds navigate using magnetic fields?

Professor Quinn: Birds use magnetic fields for navigating and how they interact with molecules of the brain. This all has to do with polarity, physics and atoms and how they are arranged.

There is one molecule called cryptochrome and it is a combination of 2 proteins - one of them is light sensitive and the other is sensitive to magnetic fields. Those 2 things mean that, If you imagine those molecules as somehow connected to the nervous system in ways we don't understand, we know they are based in the eye, but that somehow influences how nerves fire back at the eye and the pattern in which they fire allows them to create maps of where they'd be.

In the same way fish would create maps or memories in the brain linked to the smells they pick up in the rivers and they use that as a navigational tool, it is the same way with these molecules. The birds are using a combination of light which varies on where you are with respect to the equator and also magnetic lines of inclination. The angles of those lines converge from the earth's surface. The precise patterns are detected by these magnetic sensitive molecules. They use those ‘feelings’ to build up maps of where they're going, where they've been to and so on.

Interview with Dr Ameku - life as a research academic

By Sora Kamide

Dr Tomotsune Ameku is a research associate in the Gut Signalling and Metabolism Group at the Professor Irene Miguel-Aliaga Lab, MRC London Institute of Medical Sciences (LMS) Imperial College London, Hammersmith Hospital Campus. He has a biological sciences degree from Tsukuba University in Japan and a PhD in science.

Sora: What does a typical day look like?

Dr Ameku: We always do an experiment. The experiment is prepared beforehand, whether that's copulating the mice 2 weeks before to look at pregnant mice.

After the set up for the experiment is ready, we take the prepared mice and dissect them. We extract the organs and to prevent the genes and proteins from getting damaged, we fixate them to preserve the structure as faithfully as possible compared to the living state.
This is done by immersing the specimens in the fixative (immersion fixative). After doing so, we may look at certain genes that are expressed or analyse the proteins that are present.

There are also lots of meetings to attend during the day, whether that's one on one with my boss, collaborators, or colleagues. Once a week, I also give a presentation in the labs to show what I have been working on. There are also seminars which I attend, where external speakers come in - this is great because the audience can learn something new and the presenter can receive useful feedback.

Sora: What equipment is used when carrying out experimental research?

When dissecting the intestine, we look at the genetics and proteins by staining and looking at them under the microscope.

On the molecular level, we collect data from genetics, proteins and metabolites.

On the cellular level, we use staining and look at genes of interest.

On the organ level, we dissect the intestines and look at them under the microscope. For example, after female flies copulate, they need a lot of nutrients to lay eggs. Therefore, they eat more and so their intestine expands, whether that's the diameter or the length.

Sora: What organism is used to carry out research?

Dr Ameku: Most commonly we use flies, but mice are also used.

This is as both flies have similar organs and tissues as humans - this includes the intestine and even the brain!

Flies have a similar structure to humans since food that is ingested enters the stomach, then small intestine then large intestine before being expelled out the anus. The names may be different, but their structure and function are the same.

Sora: Why did you decide to specialise in the intestine?

Dr Ameku: I decided to research further about the intestine as it is essential to life. It has many functions. This ranges from absorbing nutrients as well as having many nerves, the microbiome and also having a role in immunity and defence. It is known as the 'second brain' and so our mood and behaviour changes according to our intestines! The microbiome is also very important. There are trillions of microbes in our gut and these microbes also contribute to our mood. There are also many immune cells. The muscles which move the gut and their complexity also fascinates me.

Another reason is, initially during university, I was looking at stem cells in the ovary. I was looking at what signals were needed by the stem cells and some were coming from the intestine. This piqued my interest and made me want to investigate the intestine further.

Sora: Why did you choose biology?

Dr Ameku: Initially, I had a genuine curiosity about living organisms. In high school I joined the biology faculty.

Some people who do biology have a love of certain creatures, like elephants or giraffes or insects and use that interest for their research. This was not the case for me as I personally enjoyed investigating the biological processes.

Sora: What is a good day at work?

Dr Ameku: Probably when we collect interesting data. We need to analyse data to know what they mean.

For instance, flies have around 20,000 genes and throughout experiments, we can look at all the gene sequences. From this, we can look at the difference in gene sequencing between pregnant and non-pregnant flies, for example. It is very exciting collecting new data and analysing and finding connections.

Of course, experiments don't always go according to plan. Sometimes we get negative data, but this is not a failure as we managed to reach a conclusion that the data did not fit in our hypothesis. Therefore, most workdays are good and there are hardly any bad or failed days.

Sora: What is most important when working in academic research?

Dr Ameku: Communication is probably the most important.

Experimental research is carried out on your own, but you are bound to fail and make mistakes. Your knowledge is limited and so you have to rely on others around you. This may be talking to your boss, colleagues or collaborators and even attending seminars.

By talking to others, you receive help and give help to others, and consequently your research progresses. Working all on your own won't help so reaching out for help and collaborating with people is crucial.

Sora: Where do you see yourself in five years?

Dr Ameku: After I finish my thesis in the UK, I will probably go back to Japan. This is as I want to apply the skills I have learnt in England to further research in Japan. I would like to have my own lab there and research deeper into the intestine, using not only flies but mammals as well.

Sora: What is most rewarding about your work?

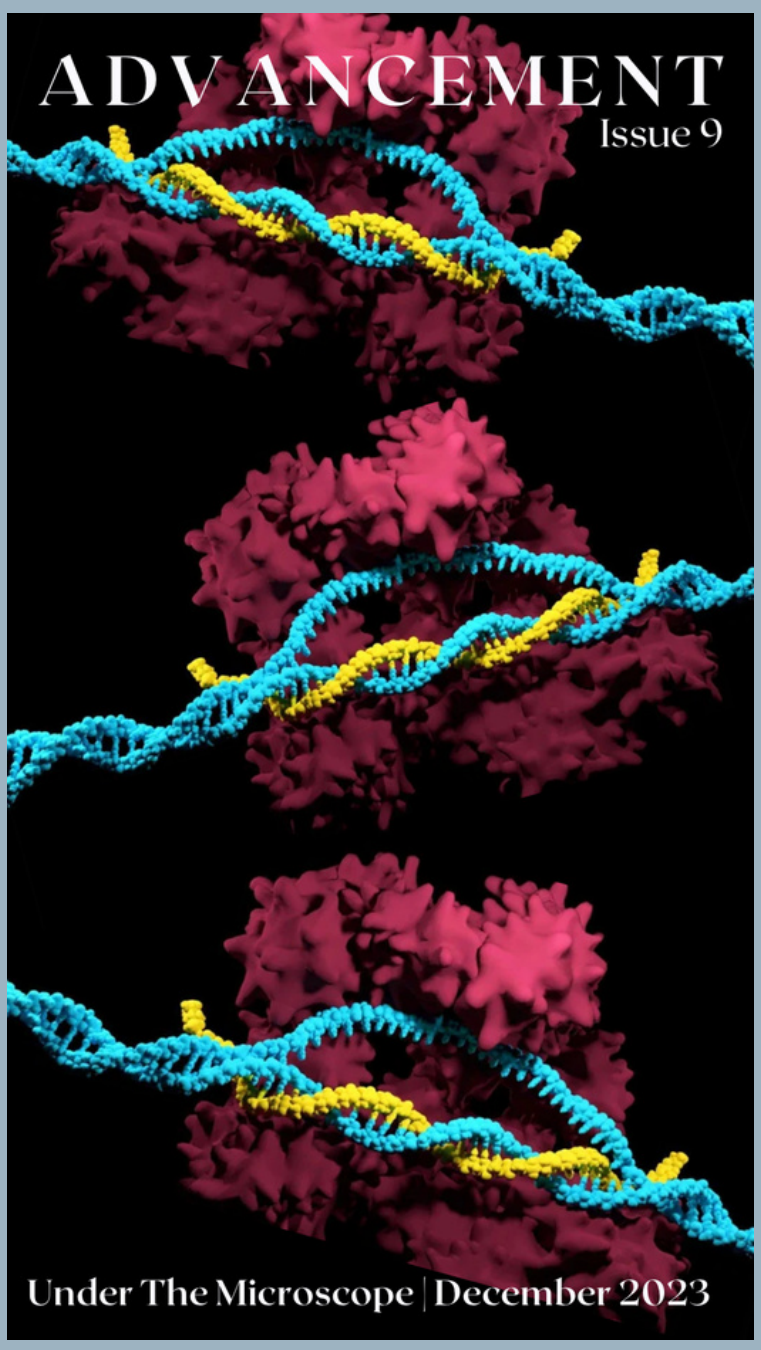
Dr Ameku: When my thesis is cited and used by other researchers and their data matches mine, it is very rewarding.

For example, during university, I was looking at flies when they copulate as they begin to lay lots of eggs. I discovered that stem cells divide more, but I was hesitant as I did not know how accurate or reliable my results were as this had not been researched before. However, when another research group in a different lab further carried out research based on my thesis and got similar results and developed it, I felt reassured knowing what I had been investigating was correct. This is a very rewarding feeling.

Sora: What advice would you give to the younger generation of budding scientists?

Dr Ameku: Continue being curious and creative. You do not have to be good at studying or a typical 'book worm'. Research is not studying. Studying is a process of learning what someone has discovered, but research is discovering something new. Of course, you have to study but research is fun and innovative, as you get to pursue your curiosities.

Thank you to everyone who gave a submission and we hope you enjoyed reading the magazine!



^A 3-D render of the CRISPR-Cas9 genome editing system

Editor in chief - Laila Samarasinghe

Copy editor - Rawnaq Islam

Copy editor - Ghazal Ershadi-Oskoui

Creative editor - Clarissa Soto-Rosa

Commissioning and Development editor - Tilly Bowden

Features editor - Sora Kamide