HARROWNET STEAM MAGAZINE

Summer 2021 Edition

Introduction

We are pleased to present the first edition of the HarrowNet STEAM Magazine. This new initiative will see the STEAM departments from participating Harrow Schools around the world work together to present you with a biannual collection of articles written by their students from Year 7 to Upper Sixth.

The John Lyon School is delighted to edit the first edition; the participating Harrow Schools will take turns in editing future editions.

We hope you enjoy reading this magazine.

Dr F. Weinberg

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Contemporary art: A ludicrous expense or reassuringly expensive?

by Freddie Strange, Upper Sixth, Harrow School, London

There is no doubt that the contemporary art market maintains an incredibly elusive relationship with value. The global art market in 2019 was estimated to be worth £50 billion. Of that, the contemporary market accounts for 15%. This percentage is an extremely large proportion considering it accounts for art only from the last forty years. In 2019 there were 70,000 lots of contemporary art sold; this is a 200% increase from 2010 and a 500% increase from the turn of the 21st century. Clearly, the contemporary art market is booming. However, it is important to understand that just like the elite of most industries, it is only a very small minority that reap the rewards that so often hit the headlines in newspapers. We are only too accustomed to hearing of records set that almost make your mind explode. Currently, Jeff Koons holds the title for the most expensive piece of work sold at auction by a living artist, Rabbit (1986) selling for $91,075,000 in May 2019. Previous to that, David Hockey ruled with his Portrait of an Artist (1972) that raked in $90,312,500 in 2018. When confronted with figures like this, it wouldn't be absurd to pack the bags and head for the studio, a product of the wonderment and mystery of the art world. In reality, the glitz and glamour of the art world is enjoyed by an incredibly small number of people. In fact, of the 70,000 lots that sold in 2019, more than half were under $1000, and more than a quarter between $1000 and $5000. Furthermore, only five contemporary artists contributed to the top 26% of 2019's overall auction revenue, with only fifty artists contributing to the top 64%.

One reason many find it difficult to attribute so much financial value to contemporary art is that it is an abstract commodity. Unlike a bar of gold, or share, that has a given numerical value at any given point in time, the value of art is entirely personal. Value is really as much as anyone is willing to pay. It is interesting to acknowledge a recent survey suggested that 30% of the UK population do not identify Roy Lichtenstein's Whaam! as art, 60% don't identify Mark Rothko's Orange, Red, Yellow as art, and a whopping 80% don't identify Duchamp's Fountain as art. This begs the somewhat profound question: what is art, and why is it so expensive? All three of those works fit into the bracket of modern art. Contemporary art is created by those that are living today, and, to broadly generalise, hopes to comment on the society around us, be it politically, socially or culturally. Indeed, it also tends to be far more conceptual, emphasizing the idea rather than the outcome. With that in mind, whilst visually we may be able, at a push, to replicate a black square, it is the journey that the artist undertook to arrive at that end point that we lack. It is possible to categorise art into three distinct sections: art that makes us say 'oh', 'oh my', and crucially, 'oh my god'.

Contemporary art, overall, fits into that third category. Charles Saatchi cemented this after his Sensation exhibition at the Royal Academy in 1997. This exhibition caused immense uproar and attracted a vast amount of media and publicity; it couldn't have turned out better. It featured artists such as Damien Hirst and his The Physical Impossibility of Death in the Mind of Someone Living (1991), Jenny Saville, Tracy Emin and Marcus Harvey. To call this show a sensation is an understatement; it is my opinion there has never been such an influential, game-changing and incredible exhibition such as this, and I would be very surprised if there was to be another on its par in our lifetime. Saatchi, having had a background in advertising and media, was well in tune with how to visually communicate with an audience. Along with his brother, he had played a pivotal role in aiding Margaret Thatcher into office, so knew implicitly how to resonate with the masses. He was at the forefront of securing 'shock art' a central position on the world stage.

Once this was procured, there are three vehicles through which prices have been raised. Firstly, there is the primary market. This consists of organisations that work directly with artists to promote and sell their work, such as Jay Jopling's White Cube or Larry Gagosian. It is in this field that the brand of the artist really starts to emerge, particularly evident in figures such as Hirst. The primary market enables artists to achieve celebrity status and has encouraged growth of the 'entrepreneurial' artist. Establishments like The Maddox Gallery claim that if you invest in their art, you are guaranteed a 25% return over three years, compared with the FTSE 100's 12.5%. Next there is the secondary market, dealing with clients and private owners. This market is dominated by auction houses Sotheby's, Christie's and Phillips, primarily in London, New York, Hong Kong and Paris. Across the globe, 39% of auction turnover takes place in America, whilst 23% takes place in the UK. The emerging market is in the east, with 28% of turnover taking place in China. In an age driven by visual media and technology, you can be anywhere in the world and be in an auction house at the same time over the phone. Finally, the third promoter of contemporary art is art fairs. The most well-known of these are London's Frieze and Switzerland's Basel. When Basel hosted its namesake event in Miami (2002), company Luna Jets had over three hundred charters a day for the duration of the fair. Fairs allow galleries from all over the world to publicise their consignments to the wealthiest outreach available.

So why is it that some spend the most absurd amounts of money on art? Philip Hook, a well-established specialist who has worked at both Christie's and Sotheby's, claims an art buyer is likely to spend 1% of their net worth on an individual piece of work. Today, more students per capita are attending universities, meaning in theory we are a more intelligent population than ever before. We are equally a much more online population, fuelled by social media. We are far more in touch with visual learning than ever before. Investing in art can be a safe bet, the market having been able to withstand the turbulences of economic hardship such as the 2008 crash and even the Coronavirus. There are two brackets into which art purchasing falls, on the one hand, some buy out of passion and emotion; on the other hand, it's a good way to diversify and broaden capital portfolios. Whether or not it's ludicrous is entirely subjective, and I urge you to ponder what you think about the contemporary art market.

Vertical Farming

by Will Tate, Lower Sixth, Harrow School, London

By the year 2050 the world's population is projected to expand to upwards of 10 billion people and feeding these extra billions will be an enormous hurdle that we will need to jump. Estimates suggest that in the next 35 years, we are going to have to produce more food then ever in history. On top of this concerning fact, the area of land we can farm over most of the world is not growing. With natural factors such as desertification (deserts slowly expanding outwards) and sea level rise, adding onto the pressure of increased urbanisation, useable farmland is shrinking. 6.3 billion people will be living in urbanised areas by 2050, so we need a method of mass production of food, in a sustainable, expandable way. This is where vertical agriculture comes in.

In 1999, Dickson Despommier, professor of Public and Environmental Health at Columbia University, set his students a challenge to create an effective and sustainable method of food production, in the hearts of cities. They produced the ultimate vertical farming concept, comprising a 30-storey building, with hundreds of kinds of fruits and vegetables growing on the upper levels, and the lower levels housing chickens and fish subsisting on the plant waste created. Now obviously nothing of that scale has happened yet. However, with the rise of more powerful technologies, such as machine learning, and costs of technology such as powerful LEDs going down, this concept might not remain just an idea on paper for long.

The whole premise of vertical farming is based around the practice of producing food on vertically stacked layers in an enclosed space, increasing the food production per unit area of surface space, whilst also lowering pesticide costs and risk of damage from natural disasters. However, there are a few ways to go about doing just that. The two main types are Hydroponics and Aquaponics.

Hydroponics refers to the technique of growing plants without soil. In hydroponic systems, roots of a plant are submerged in a liquid solution containing macronutrients (nitrogen, phosphorus, sulphur, potassium, calcium, magnesium), eliminating the need to replace the growing materials such as soils. A study conducted by the International Journal of Environmental Research and Public Health found that hydroponics increased the yield per area of lettuce by around 11 times, requiring 13 times less water. This is down to the fact that there are no growing materials there to absorb useful macronutrients, as well as no competitive 'weeds,' such as emerge in fields. Due to its advantages, it is the dominant growing system used.

Aquaponics refers to fish farming and hydroponics combined, then integrating the production of terrestrial plants with aquatic organisms, fish. The closed loop system mimics nature, with nutrient rich wastewater from fish tanks being used to water the crops. The water from the fish contains considerable amounts of ammonia, a chemical that unless treated is not good for a lot of crop plants. So, wastewater is led through a bio filter, converting the toxic ammonia to nutritious nitrates, that the plants then use to grow. Moreover, the plants consume the carbon dioxide produced by the fish, as well as the warmth of the water tanks, saving heating costs at night. This cycle can then continue repeatedly in its closed loop form.

So now you have your concept, where can you implement it? Effectively, the most sustainable way forward is to occupy abandoned buildings on brownfield sites such as warehouses and old factories and transform them into sprawling vertical farms. Thus, not encroaching on any new land. Other concepts such as utilising old shipping containers are popular and on the rise. With LED lighting, smart controls, and monitoring sensors for the stacks of hydroponics, each individual container, a chamber, offers a chance to individualise the climate conditions and lighting, to perfect the requirements of each plant growing. However, if you are not into the futuristic stacked city look, there is also the possibility of deep farms: renovated and refurbished underground tunnels or abandoned mines whose temperatures and humidities are constant compared to the surface, as well as having, in many cases, direct access to groundwater. Offering low cost, high density food production, right beneath a sprawling metropolis, this concept, coupled up with automated harvesting systems such as robots, could result effectively in a self-sufficient hole, in which seeds go in, and organic leafy green food comes out.

Underpinning all off this, is technology, with quite possibly the most important technological advancement necessary for this future of vertical farming being Controlled-Environment Agriculture (or CEA for short). Ranging from a simple greenhouse, to industrial warehouses, CEA controls vital factors such as temperature, water, nutrition, humidity, light, and even gas (such as carbon dioxide) concentration, all vital to maximum crop production. This modifies the natural environment of a room / tunnel / warehouse, and transforms it into the high yielding machine that we will need and rely on increasingly if we want to bolster our crop production. Part of the CEA system, and one of the most crucial factors, is the lighting, and lighting control. LEDs are now becoming powerful and efficient enough to effectively be integrated into systems like vertical agriculture. Abilities to control the levels of light emitted, as well as the specific wavelength, offer quite literally a bright future. With LEDs we have the potential to emit just blue and red light, which are the wavelengths needed for photosynthesis, because of course the green light we see on plants is the light reflected and is not required. LEDs can do all this extremely efficiently, with barely any heat loss, in a more compact unit, with the bonus that they last longer than conventional lights and neon lamps.

A brilliant example of all of this in action is the London company, Growing Underground, which in 2015 began the production of produce in abandoned underground WWII tunnels. They combine deep farms and hydroponics to offer a wide selection of leafy greens and serve up fresh produce to restaurants all over the city.

Though, right now, vertical farms still require a huge amount of energy to run, as efficiency of technology increases, and renewable energy production flourishes, we have the opportunity to use more and more effective CEA. Leading to rising, efficient food production, vertical farming, in whatever form it takes, offers a hopeful future and is likely to become more widespread across urban and rural sites alike. It is the strategy we need to utilize to jump the hurdle, feeding the ever expanding, every demanding, ever hopeful world population.

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Can we solve food insecurity with GMOs?

by Cody Xu, Lower Sixth, Harrow School, London

Genetically modified organisms, or GMOs, describe any organism which has gained heritable improvements, via either genetic engineering or other more traditional methods[1]. Here, traditional methods refer to something which we have been doing to crops and livestock for centuries: crossbreeding, the creation of offspring that combines the traits of two species, and selective breeding, the creation of offspring that will only have desirable traits. In fact, from bananas to cabbages to beef, almost every grocery we buy at the supermarket has been genetically modified in this way some time in history. Food insecurity is defined as the disruption of food intake or eating patterns[4] and the latest available estimate by the United Nations estimates that 821 million people worldwide, or one in nine people, were undernourished due to food insecurity in 2018[2]. With the ever-rising population, I believe that modern genetic modification techniques could play a role to a great extent in ensuring global food security.

The two most popular methods of genetic engineering nowadays are the TALEN and CRISPR-Cas9 technologies[6]. TALENs, or transcription activator-like effector nucleases, comprises a nuclease, an enzyme which can break the bonds between nucleotides in DNA, and a programmable DNA-binding site[7]. Similarly, the CRISPR (clustered regularly interspaced short palindromic repeats) system is made up of a protein called Cas9, equivalent to the effector nuclease in TALENs, and a guide RNA strand (gRNA), which tells the Cas9 protein where on the DNA to cut[8]. In both methods, scientists can construct their own DNA-binding site using the rule of complementary base pairing to target the section of DNA that they want to edit. After a double strand break (DSB) has been made, we can utilise a naturally occurring mechanism known as homologous recombination to insert the desired gene. This is when the break in the DNA triggers the cell to find a similar strand of DNA to act as a template that can repair the DSB[6] and so if we accompany the TALENs or CRISPR-Cas9 complexes with a strand of DNA containing the gene that we want, the new gene will automatically be inserted into the DSB[8]. These modern methods are the same as traditional methods in the sense that organisms are made to have new genes which give them more desirable traits. However, with newer technologies, we can pinpoint the sections of the genome that we want to edit, allowing us to remove or insert new genes with much higher accuracy, specificity, and efficiency.

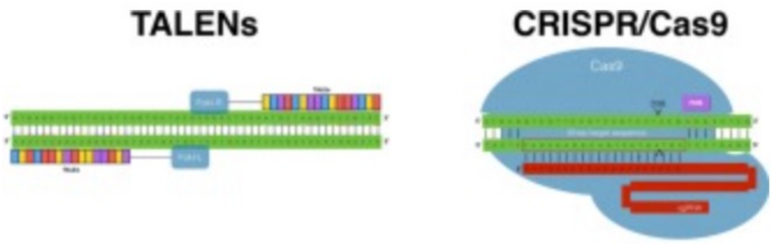

Image curtesy of Science Direct[14]

So, how will these genetic modification techniques help us solve food insecurity? The Food and Agriculture Organisation, a branch of the United Nations, identifies the main causes of food insecurity to be poverty, natural disasters, food distribution, population growth and conflict[3] and GMOs may be the answer to some of these. Firstly, we are able to genetically modify crops to be more nutritious through biofortification, a process that increases the nutritional value of food[13], and this will ensure that those who live in poorer places where food insecurity and malnutrition is high can get enough vitamins and minerals in just a few crops, ensuring a more balanced diet.

Modern GMOs can also be much easier to grow than conventional crops. For example, they can be made resistant to identified diseases, allowing there to be a stable, affordable supply of food. Similarly, especially since climate change is causing more extreme weather events, crops can be made more resistant to droughts or extreme temperatures to ensure a constant supply. During the turn of the millennium, Syria experienced a devastating drought which resulted in severely insufficient crop supply, causing a widespread famine[9]. By genetically modifying the crops to be drought resistant, or at least be able to recover from a period of water deprivation, we could prevent this from happening in the future. Furthermore, with disease and drought resistant crops, farmers are more likely to expand production with a growing population as they can foresee stable profits. This means that by using GMOs, we will be able to keep up with the increasing demand of a growing population.

However, whilst there are many advantages to using GMOs, there are inevitably some issues, too. One concern is that there may be reduced genetic diversity in the environment due to outcrossing, which is 'the unintentional breeding of a domestic crop with a related plant'[10]. Whilst this is often a good thing for plants, if this were to happen with crops that have been genetically modified to have enhanced survival abilities, it could cause the plant to spread and grow uncontrollably in the surrounding areas[11]. This could wipe out other less competitive species and would have serious consequences for biodiversity and the stability of ecosystems. However, scientists have already begun looking into this and have found little evidence to support this theory. Having said that, we still need to be very cautious and methods of prevention have been set out, such as requiring two GMO plants to be crossed in order for the offspring to have the modified gene[11]. A reduction in biodiversity within a species could also result in a lack of species resilience to environmental changes, whether biotic or abiotic. So, for example, if there were to be a new disease that the GMO had not been programmed to be resistant against, the lack of genetic variation would mean that the entire population would be wiped out very quickly. Another force that is slowing the widespread use of genetic modification is worries that people have about its safety. However, according to Eric Sachs, a spokesperson of a leading developer of biotech products, 'transgenic products go through more testing than any of the other foods that we eat'[5]. For example, in the US, if the data for a GMO is not sufficiently equivalent to its non-GM counterpart, then it will not be allowed to enter the market until more testing has been done[5]. This, along with multiple scientific studies[12] tells us that the consumption of GMOs is no more risky or unhealthy than the 'natural' foods, which, as we have already discussed, are likely to have been genetically modified in the past anyway.

All in all, I believe that the responsible and sustainable use of GMOs is a viable option in tackling food insecurity and malnutrition, as it can provide us with a more stable and nutritious food supply, whilst still being affordable. If we are able to give the public enough confidence that GMOs are safe for consumption, as well as ensuring that GMOs do not have negative impacts on the environment, then we may be one step closer to solving food insecurity.

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CRISPR

by Kevin You, Lower Sixth, Harrow International School, Bangkok

NOBEL PRIZE IN CHEMISTRY 2020

The 2020 Nobel Prize in Chemistry has been awarded to Emmanuelle Charpentier and Jennifer Doudna for their pioneering work in developing CRISPR, a tool for gene editing.

But what is CRISPR? How was it discovered and why is it revolutionary? To answer these questions, we need to first understand the basics of DNA, the "code of life".

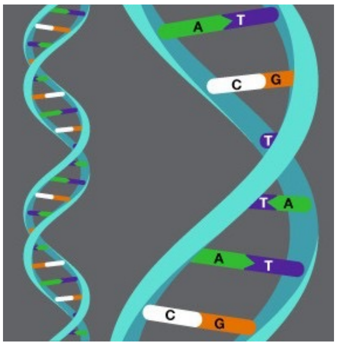
WHAT IS DNA?

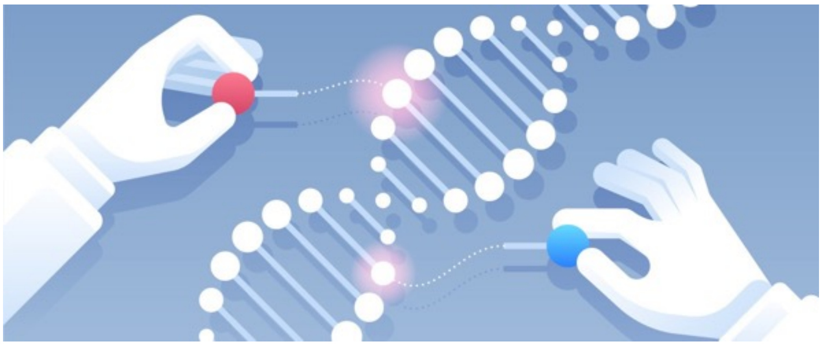
Why is DNA the "Code of Life"?

Organisms are made up of cells. Each (eukaryotic) cell contains a nucleus which stores the genetic information of the organism in the form of DNA (deoxyribonucleic acid), which is a double stranded helix. DNA is made of "codes" called base pairs (ATCG), where "A" on one strand always corresponds to "T" on the other and similarly, "C" always corresponds to "G".

For example, the corresponding pairing for a sequence "AACTGG" in a DNA molecule must be "TTGACC". This sequence, "AACTGG", could be a gene responsible for a particular feature, maybe blue eyes or colour blindness or something else entirely.

A functional sequence is then called a "gene" which is like an instruction manual from which proteins are made, so a feature could be expressed. To actually make the protein, DNA is first turned into RNA - a single strand (effectively, half of a DNA strand) - which could be read by ribosomes ("protein factories") and made into the protein.





HOW CRISPR WAS DISCOVERED

The CRISPR system was discovered in an experiment studying the activity of bacteria, which are simple, single-celled organisms. Bacteriophages (phages) are viruses that only kill bacteria, and they infect bacteria like a "ticking time bomb".

When a phage infects a bacterium, it injects its viral DNA into the host which replicates inside and does not stop replicating until the bacterium is filled with new phages. This usually takes only a few minutes. At this stage the bacterium bursts and releases the new phages.

Some bacteria may survive a phage infection. Surviving bacteria cut sections of the phage (viral) DNA and insert them into their own chromosome (DNA) as a defence mechanism. To recognise these inserted phage DNA as "foreign", repeated recognition sequences of DNA would be added on either side of the insertion, which is why the sites are called CRISPR (clustered regularly interspaced short palindromic repeats). This mechanism records DNA of past phage infections, much like a genetic vaccination card. These vaccination cards are then passed onto the next generations when the bacterium divides, thus allowing these protections to be inherited.

THERAPEUTICS TO ENHANCEMENT?

We also have to consider how CRISPR can potentially be used to enhance human traits in the upcoming decades.

These could include stronger bones, less susceptibility to cardiovascular diseases or even "desirable" properties — taller, perfect eyesight etc., leading to "Designer Humans".

Currently, the genetic information that would give rise to such properties is not completely understood, however CRISPR is a tool which allows the ability to edit these when they are known better.

Nonetheless, the unintended consequences from mistakes and intended impacts of such scientific breakthroughs must be carefully considered, along with the ethical questions coming along with these capabilities.

BACTERIA FIGHTING BACK

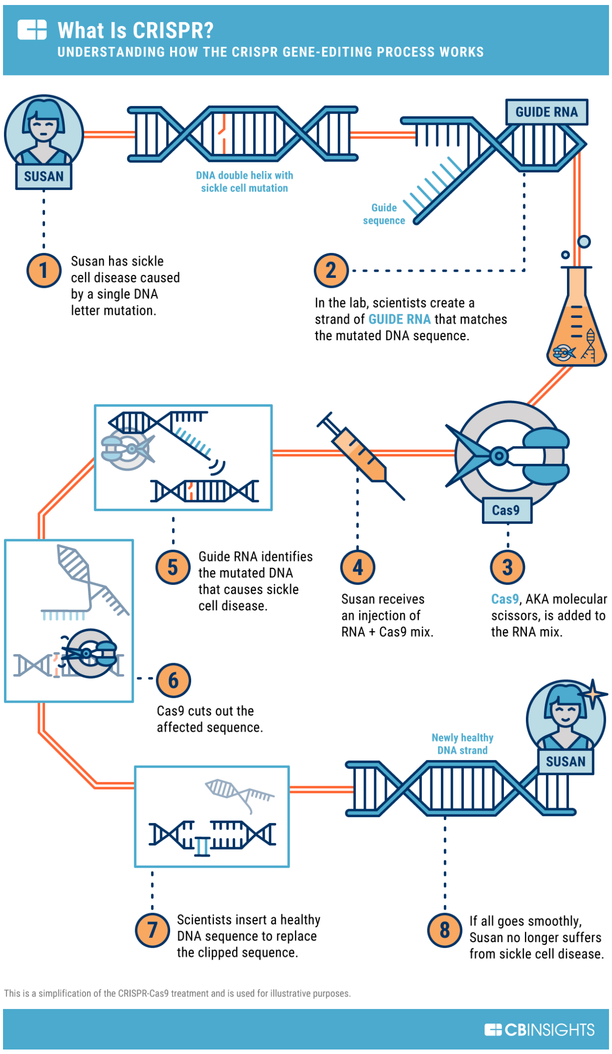
A molecule of RNA that has a matching sequence with the recorded viral DNA is produced. This RNA molecule combines with an enzyme called CRISPR associated protein 9 (Cas9), forming an RNA-Protein complex which functions like a "sentinel" in the cell — it scans all the DNA in the bacterium for traces of invaders.

The RNA is much like a "Wanted Notice", it guides the complex to find DNA with a matching sequence. When the same phage infects again and injects its DNA (having a matching sequence with RNA) the Cas9 "sentinels" detect this and function as molecular scissors. Cas9 then precisely cuts out the matching sequence in the phage DNA.

As cuts are made at different sites, the phage DNA degrades. It can no longer be used for viral replication as the "instruction manual" to make the virus is broken. Thus, the bacterium has defended itself from this particular bacteriophage.

Furthermore, this protein complex is programmable, meaning we can decide on what the matching sequence is, and make the protein complex recognise a particular DNA sequence then make a break at that site.

Our cells can detect breaks in DNA and repair it, by pasting together the ends or integrating new genetic information at the cut. So, if we were able to programme the CRISPR technology to make a break precisely at a mutation - causing colour blindness, for example - then we can trigger the cell to repair that mutation after cutting it out, ultimately correcting mutations causing genetic diseases.



Why reusable rockets are more than just a publicity stunt

by George Ferguson, Lower Sixth, Harrow School, London

Most of the population view reusable rockets as nothing new. After all wasn't the space shuttle a reusable rocket way back in 1981? Well the short answer is no, it was not really reusable. The actual cost was $152 million per flight. Today's reusable rockets cost about $4 million per flight. This dramatic cost reduction makes space exploration and exploitation a commercial possibility for companies not just nations.

How do reusable rockets work?

One of the critical factors in developing genuinely reusable rockets has been the exponential improvement in computing power at comparatively low cost. So called 'Moore's Law states that we can expect the speed and capability of our computers to increase every couple of years, and we will pay less for them. Another tenet of Moore's Law' asserts that this growth is exponential.

For a rocket to be reusable it must be able to land. To explain how this is possible we will be looking at the SpaceX Falcon 9 rocket. Although the Falcon 9 rocket is not entirely reusable it is able to reuse the first of the two stages of the rocket. After the rocket has reached its terminal altitude the Falcon 9 will jettison its bottom half, which then fires its own single engine to take the payload into orbit. The top half of the rocket returns to Earth. To do this the top half of the rocket is equipped with small thrusters near its nose, these thrusters fire and flip the rocket to prepare it for the return journey. After the rocket has flipped over, three of its engines reignite to decrease the rocket's re-entry velocity. These engines then fire again as the rocket nears the landing platform. Over the course of the return journey the engines manage to slow the rocket from its top speed of 4,700 km/h to its landing speed of 20 km/h.

Slowing the rocket down is only part of the challenge. After slowing down, the rocket has the difficult task of steering. For this the rocket uses grid fins that look a little like the mesh of a tennis racket which are the size of a typical kitchen table. After the first firing of the engines the heat resistant wings pop out of the side. Working the same way as a skydiver's hands and using minute movements these fins steer the rocket towards the landing pad. This is where the use of a supercomputer is critical to success as the rocket needs to counter the unpredictable effects of the ever-changing air pressure, wind velocity and weather. This is the hardest stage for reusable rockets and the reason why reusable rockets have proved so challenging to build successfully.

The supercomputer on the Falcon 9 rocket has a dozen sensors that measure the rocket's orientation, position, velocity, acceleration, and altitude. All these need to be calculated in a fraction of a second and then the grid fins need to be adjusted so that the rocket still lands on the landing pad. Because of the unpredictability of all the different forces involved there can be no set plan for the rocket to take off and land.

To absorb the landing forces as the rocket touches down the Falcon 9 rocket uses landing legs made of carbon fibre, these legs are not reusable, and they crush upon impact much like the crumple zone of a car.

What are the implications of reusable rockets?

Whilst improvements in technology have brought us much closer to making totally reusable rockets a reality, the most important advance has been in lowering the cost of getting payloads into orbit.

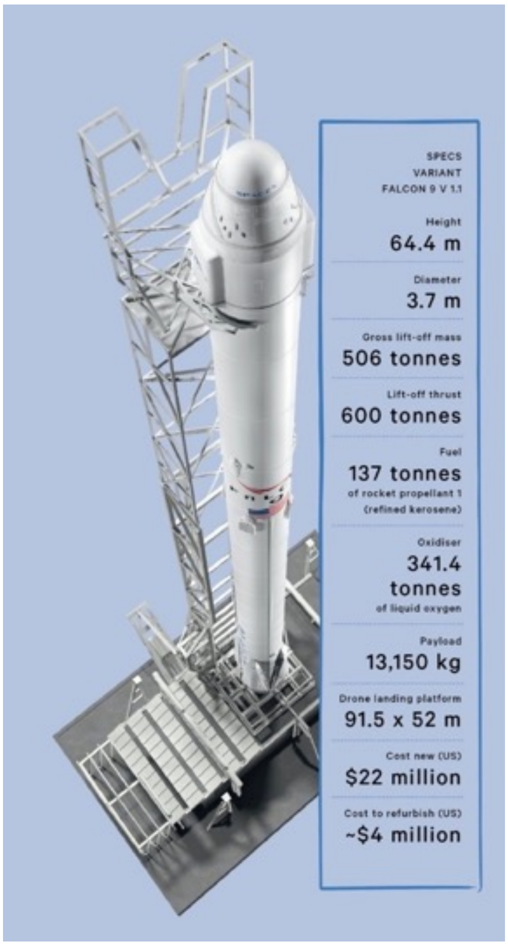
The average cost for NASA to send a rocket into space is $152 million. By contrast the Falcon 9 rocket costs only $4 million dollars to refurbish and to send it back into space. This means that the Falcon 9 rocket costs about 2.7% of what it costs for NASA. This means the cost of building large scale structures such as the International Space Station has dramatically decreased. Building large scale structures in space and being able to provide the manpower required to man and maintain them is becoming a commercial possibility for companies and nation states.

As the "space race" hots up much greater regulation and compliance will be needed to avoid space becoming a chaotic free for all. More than 70 countries purport to have an active space programme and as more commercial carriers come into the picture as reusable rockets become cheaper and more widespread, the opportunities and risks will become greater.

The face of space exploration is changing rapidly as new partnerships are formed. Recently there has been a partnership between NASA and SpaceX. This is going to decrease the cost of the Artemis Program. The Artemis Program is NASA's plan to send a crewed mission to the moon by 2024 as well as establishing an outpost by 2028. NASA's partnership with SpaceX will not only decrease the cost of each launch but provide new exploratory and commercial opportunities for both parties. They are not alone in seeing exploratory and commercial opportunities in space. Amazon and Virgin have their own space programmes and five African countries now have active space programmes, something that would have been unthinkable 10 years ago.

What is the next step?

At this point the next step is anyone's guess. On the exploratory front manned missions to the moon and Mars are likely whilst on the commercial front trips to outer space for the wealthy few and communication advances like the Starlink promise mobile communication anywhere on Earth for the first time. Alongside these advances come significant risks and even the potential for armed conflict as commercial companies and nation states seek to exploit the opportunities that space provides. The USA recently established a space arm of the military and it is likely that other countries will not be far behind. The new frontier of space promises to be every bit as pioneering and controversial as the land grabs and empire building that previous centuries witnessed. Let's hope lessons from the past have been learnt.



Credit: Anthony Calvert

How we could use tethers for space travel today!

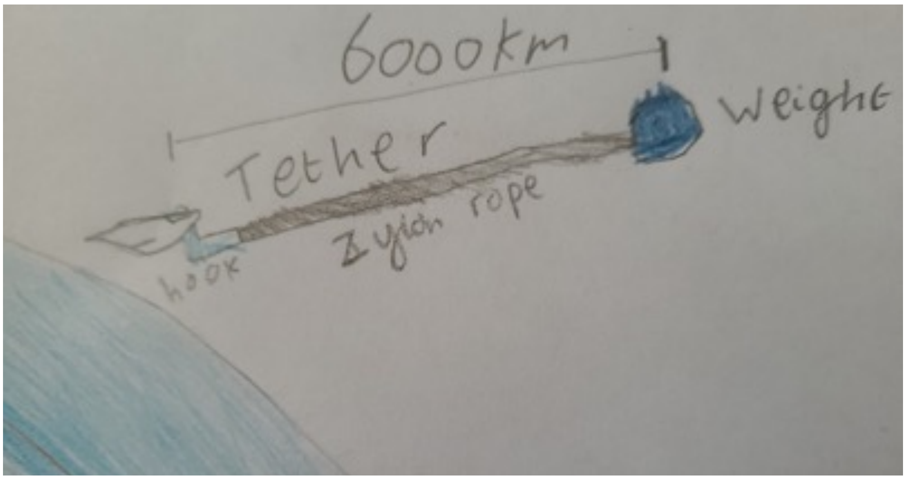
by Liam Louiset-Hall, Year 7, The John Lyon School, London

Space travel today is expensive and dangerous. Every time someone is sent into orbit or to the moon, NASA, SpaceX and the like are rolling a dice praying that their ship won't blow up. But there is a safer, cheaper, and easier way to travel from planet to planet that doesn't seem too far away: skyhooks.

Only about 80 years ago, space travel was science fiction. Nowadays, trips into the Earth's orbit are a regular occurrence, whereas visits to the moon and the planets are still very rare. The furthest that any human has gone is to our moon, which was achieved by Neil Armstrong and Buzz Aldrin in 1969; in the intervening 52 years no human has travelled further. The reason for this can be shown by a comparison of the time and distance of the moon to Earth compared to the other planets in the solar system:

Journey	Distance (Millions km)	Estimated Voyage Time
Earth to the Moon	0.4	3 days
Earth to Mars	78.3	9 months
Earth to Jupiter	628.7	1 year 1 month
Earth to Saturn	1,316.4	3 years
Earth to Neptune	4,351.4	8 years

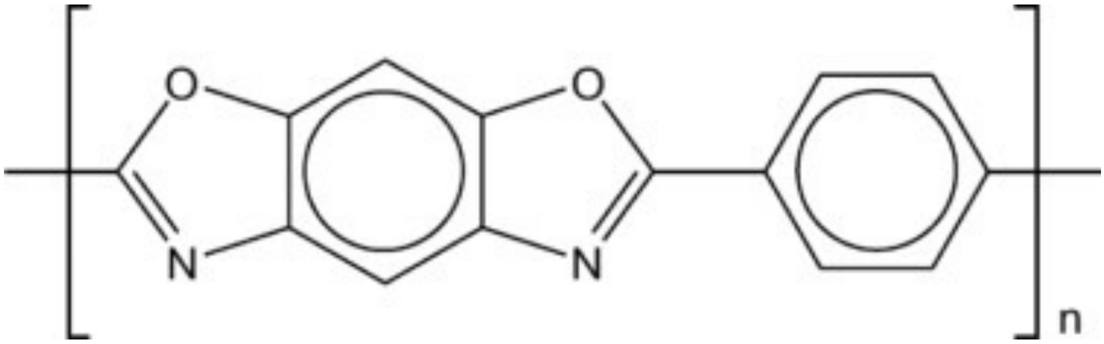
These long journeys could prove fatal for any human travelling because of the radiation exposure from the sun; on Earth we are protected by Earth's magnetic field. An additional hindrance is the amount of fuel needed to get to the destination and back. This means space travel beyond the moon using current rocket technology is too expensive.



How does a skyhook work?

A skyhook is a satellite orbiting the Earth with a long tether, thousands of kilometres long. The end of the tether would start in Earth's atmosphere 80km above the surface. This would mean that a spaceship would only have to travel 80km up using its own fuel and the tether would pull it up thousands of kilometres into space. However as the tether is not touching the ground, when we use it to pull up ships it will go down due to Newton's third law. To stop this we can make the tether spin, this means that as well as bringing spaceships up we can slow down the spaceships returning to Earth. The momentum the skyhook loses accelerating the spaceship into space is returned to the skyhook by decelerating the returning spaceships back to Earth.

What are skyhooks made of?



Zylon molecule

The cable would need to be very strong, steel would need to be too thick to cope with the stress of the job. The cable would be made out of a material called Zylon. Zylon is 1.6 times stronger than Kevlar, which is often used in bullet-proof vests, and as such would be useful for the high stress the skyhook would be faced with. It would need to be a thick rope of Zylon with lots of extra fibres so that as space debris and mini meteor-ites cut through the cord it would still be strong enough to work. This material already exists and is used in Formula 1 cars; the problem will be to make it thousands of kilometres long.

By building skyhooks around each planet, we can create a network around the solar system from Mercury to Neptune. This allows us to mine resources on the planets, moons, and asteroid belt; these materials can be flung back towards Earth and Mars. Skyhooks would allow us to move around the solar system with very little fuel cost. They are a better alternative to rockets, reducing costs and travel times enormously; the trip to Mars would be three months instead of nine.

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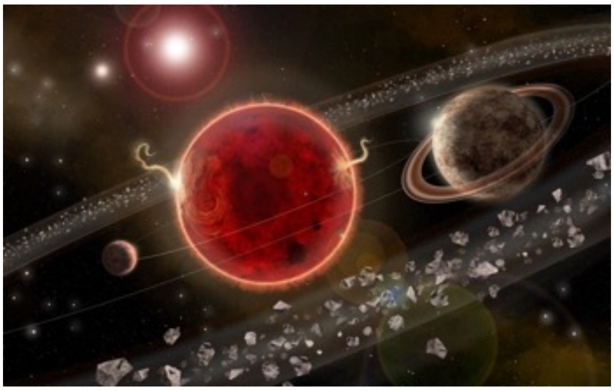
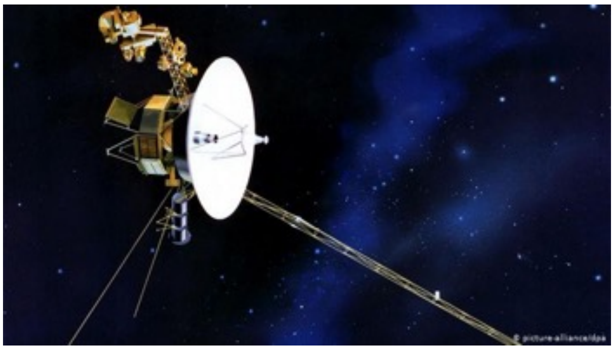
Will humanity achieve interstellar travel in our lifetime?

by Mosachi Suwannaroj, Year 11, Harrow International School, Bangkok

I'm sure that many of you may have dreamed about visiting another planet or star. You've probably heard the phrase "born too late to explore the world and born too early to explore the universe," which suggests that our ancestors explored the unknown parts of the world while our descendants will be exploring the unknown parts of our universe, leaving us in the 21st century as the generation with little exploration to accomplish. But is this really the case? Could our civilization actually reach out and touch another star during our lifetime?

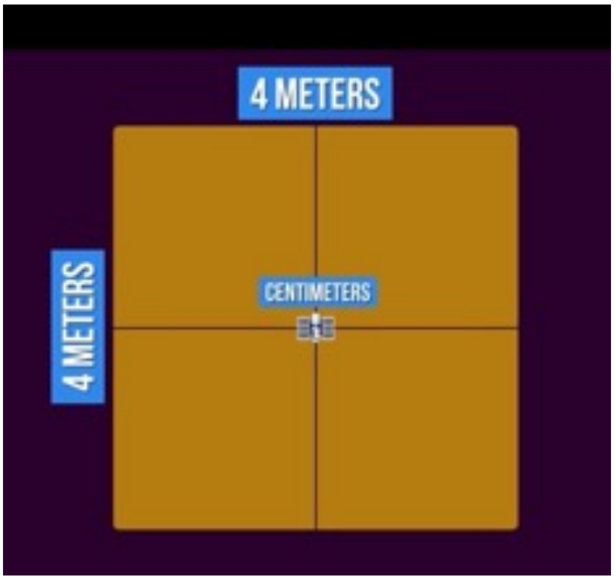


Interstellar travel refers to "the travel by interstellar probes or crewed spacecraft between stars or planetary systems in a galaxy."

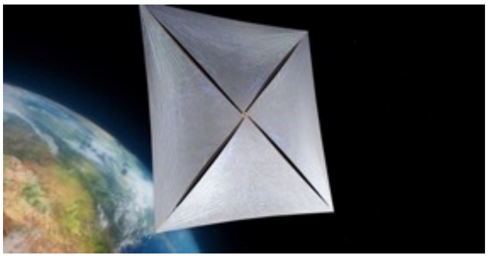


For context, the closest other known star to our solar system is called the Proxima Centauri which is still 4.25 light years away from us. To put into scale with our current technology, the Voyager 1 space probe is the furthest away from Earth that a man-made object has ever been so far. It is 140 astronomical units away from the sun, meaning it is 140 times further away from the sun than Earth is. To achieve this distance, Voyager uses the gravity from both Jupiter and Saturn to reach a speed of 17 km per second. However, even at this far away distance and speed, it would take Voyager another 73,000 years to reach Proxima Centauri.

In 2018 NASA launched another space probe which will become the fastest moving object humanity has ever created. It is called the Parker Solar Probe and it was sent out to study the outer corona of the sun. The probe utilizes the repeated gravity from Venus to enter an elliptical orbit around the sun and at its closest point to the sun in orbit, the probe will achieve a velocity of 200 km per second. That's fast enough for the probe to travel around the equator in 3 minutes and 24 seconds. However, at this amazing speed it is only a tiny 0.07% of the speed of light which means that at this speed it would take the probe over 7,000 years to reach Proxima Centauri.



With our current technology, the most likely idea which will enable us to at least see another star system up close is called Breakthrough Starshot.



If successful, Breakthrough Starshot will be one of the most important events of the entire 21st century. The idea is to develop a tiny ship on the scale of centimeters, weighing only a few grams, with a sail attached to it. It will have a dimension of 4X4 meters and there will be a thousand of these tiny ships and sails to be created and all of them will be lifted into orbit by a larger mothership on a conventional rocket. Once in orbit the mothership will deploy one tiny ship and sail at a time. The sail attached to the tiny ships works like the sail does on a boat on Earth but instead of the wind providing the necessary propulsion it will be a huge 1 square kilometer ground-based array packed with high powered lasers. These lasers will all concentrate their collective power onto the tiny sails of the ships one at a time. This will be capable of accelerating the vessels up to 20% of the speed of light in only 10 minutes. Once all 1000 ships were deployed it should be able to reach Proxima Centauri in about 20 years. Since the scheduled flight time is in the year 2036, this means that the first human made space craft could arrive in another solar system in the year 2056.

Although, there will still be problems with this project. Firstly, any collision at that speed would destroy any of the craft, which is why at least 1000 of them are going so at least some of them will make the journey. Furthermore, the square kilometer laser array on the ground will use up 100 gigawatts of power per each sail that it propels. This is a massive amount of energy which is difficult to obtain but still possible. Finally, the cost of the project is estimated to be at 10 billion dollars. This may seem like a lot of money at first but considering NASA's project for 2018 is 19. 1 billion dollars and the cost for the International Space Station is 150 billion dollars, taking 10 billion out of these budgets will be reasonable. Perhaps, when you consider that there is a planet that orbits inside the habitable zone of Proxima Centauri called Proxima Centauri B. The ships from Breakthrough Starshot will be able to take pictures of this planet that could reveal oceans, continents and other surface features. If it's true that Proxima Centauri B is truly habitable, Proxima Centauri B will become the main focus of future human colonization which will potentially secure the future of human civilization in the universe. 10 billion dollars will be a very small price to pay considering those factors.

For us in the 21st century it is most likely that humans will never visit another star in our lifetime, but we can still take pride to set up the foundations for our descendants to become future explorers and visit another star that will carry our legacy with them just like the quote "any society grows great when old men plant trees whose shade they know they shall never sit in."

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Bitcoin Explained

by Josiah Wu, Lower Sixth, Harrow International School, Hong Kong

SERIOUSLY, WHAT IS THIS?

In 2017, there was a huge frenzy surrounding Bitcoin. Not only did it attract attention from economists and investors, it also became a hot topic amongst the general public. In fact, throughout 2017, questions like "How to buy Bitcoin?" and "How to mine Bitcoins?" were in the Top Ten list of the most trending 'How to' queries on Google.

But what is Bitcoin? To start, we need to understand that Bitcoin is, in fact, a type of cryptocurrency. Cryptocurrency is a digital currency; however, unlike the conventional currencies we know (such as US dollars or UK pounds), cryptocurrency is not controlled by any central authority. If I wanted to make a transaction with Bitcoin, the transaction would not be verified by any bank or government, but it would instead rely on a network of computers that govern transactions.

Cryptocurrencies rely on a system called Blockchain, which is an accessible public ledger that records all the valid transactions made between users. It is designed in a way such that it is nearly impossible for anyone to tamper with it.

Blockchain consists of two parts: the 'block' and the 'chain'. There is a long list of valid transactions within each 'block', and each block is labelled with an individual identity called 'hashes'. The 'chain' connects one block to another to form a blockchain.

Nobody owns or controls this public ledger. Instead, volunteers (known as Miners) update the public ledger by creating a new 'block' and connecting it to one of the old blocks, helping the system circulate and function.

The first person to update the ledger is rewarded with approximately 12.5 Bitcoins (~US$100,000 after conversion, as of Feb 2019). However, updating the public ledger is a laborious job.

When a deal is struck and confirmed, the transaction is announced publicly into the Bitcoin network. Miners must first gather and verify one megabyte worth of those transactions into a block, and then solve an extremely difficult cryptographic 'puzzle' before they can upload their block onto the blockchain. This whole process is known as 'mining'.

CRYPTOGRAPHIC HASH FUNCTION

To understand this 'puzzle', we need to first grasp the idea of a cryptographic hash function. This function converts a string of plaintext into a hash, or a string of binary numbers (also known as 'bits').

The one Bitcoin uses is the SHA-256, which is a common cryptographic hash function used for internet security.

One characteristic of this cryptographic hash function is that while every input has a unique output, a minor change to the input affects the output drastically. For example, if we want to convert the word "Bitcoin" in SHA-256, it would output:

b4056df6691f8dc72e56302ddad345d65fead3ead-
9299609a826e2344eb63aa4
(*in hexadecimal, for easy comparison)

However, changing the input by replacing the upper case "B" to lowercase "b" yields:

6b88c087247aa2f07ee1c5956b8e1a9f4c-
7f892a70e324f1bb3d161e05ca107b
(*in hexadecimal, for easy comparison)

SHA-256 is also computationally infeasible to program in the reverse direction. That is, if given the output, it would be immensely difficult to determine the matching input even with the world's most efficient computers.

PROOF OF WORK

Cryptographic hash functions are used to generate hashes for each block. Each hash is dependent on several characteristics within its respective block; this includes its transaction history, its timestamp, and a matching input (which will be discussed later).

Besides this, the hash of the previous block is also involved in the generation of the hash, hence every block is interconnected with each other. These linkages, therefore, form a 'chain'.

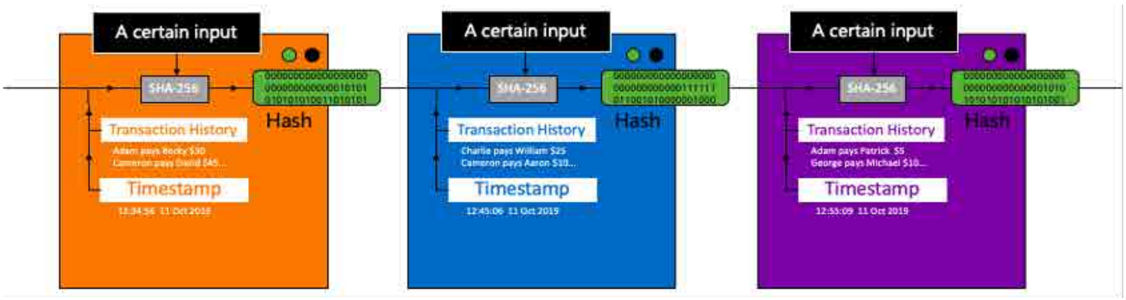


***Figure 1:** An example of a blockchain (Source: Josiah Wu)*

This is where the 'puzzle', as mentioned earlier, comes into play. The problem is to find a particular input such that it induces a hash with a specific amount of zeros at its beginning. This is known as the Proof of Work (PoW).

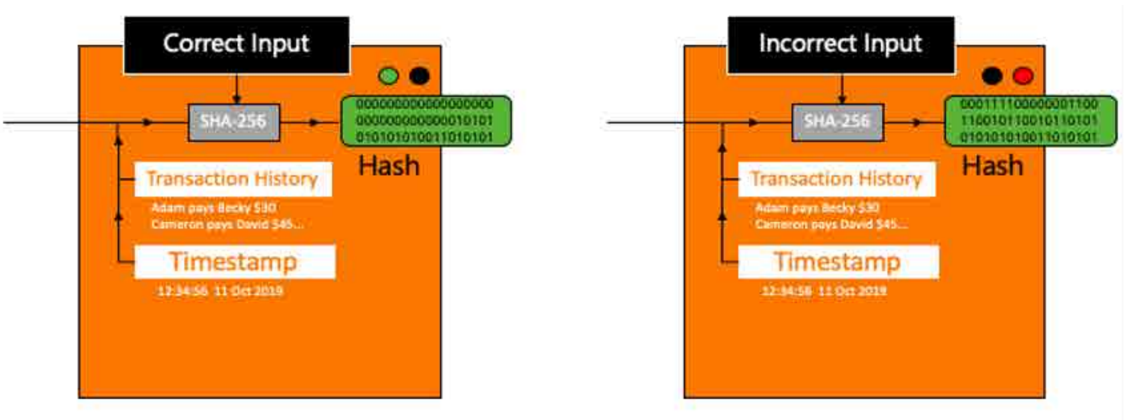


***Figure 2:** An example of a correct and incorrect input generating the correct hash and incorrect hash, respectively. (Source: Josiah Wu)*

The required amount for Bitcoin is 30 leading zeros. What is the probability of finding such hashes in a single try? We can find this out by doing the below calculation:

$\frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} \ldots = 1/2^{30}$ or 1 in 1.07 billion

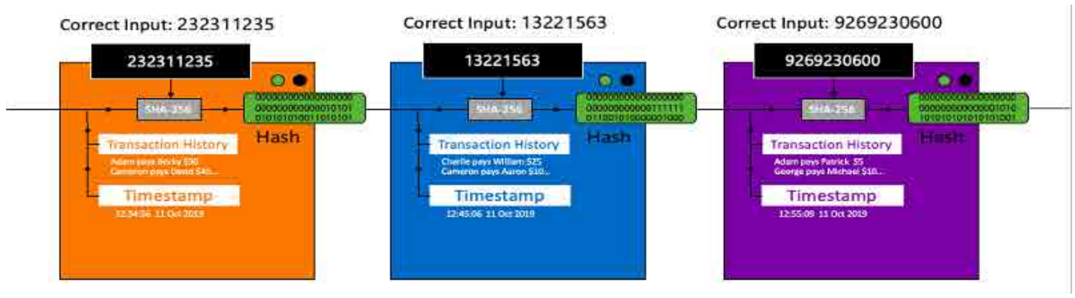
For comparison, the odds of winning a jackpot in Mark Six (a legal lottery in Hong Kong) is 1 in 140 million. This demonstrates that the chances of acquiring the correct input is remarkably slim.

Since solutions to reverse-engineer cryptographic hash functions are yet to be found, Miners are left with no option but to use the trial-and-error method - randomly guessing the input until the correct one is found. Hence this system enables fair competition between the 'miners' and incentivizes voluntary updating of the ledger.

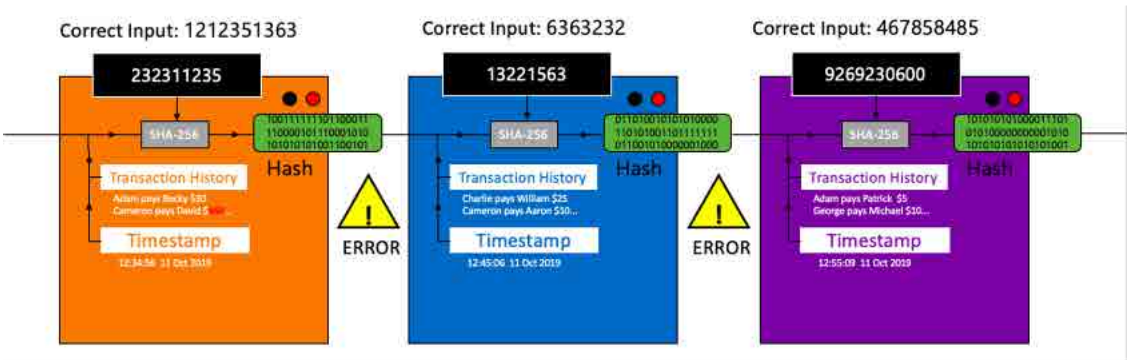
WHY IS PROOF OF WORK NECESSARY?

Proof of Work is necessary because it inhibits anybody from altering the contents within the blockchain without getting caught.

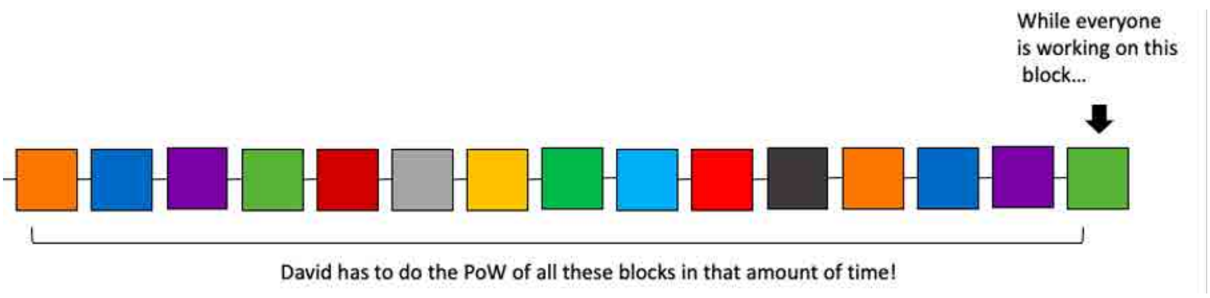
Imagine David, who is very greedy, wants to edit the transaction history so that Cameron pays him $450 instead of $45.



David hacks into the Bitcoin system to edit the transaction history. However, he soon realises that he has run into trouble: as the transaction history is changed, the hash is affected, therefore making it invalid. This, in turn, affects the hash of the neighbouring blocks (as the previous hash is needed to generate a new hash).



In an attempt to reverse this, David then tries to recalculate all the matching inputs to ensure all the following hashes are valid, as if nothing has gone wrong. However, he has to redo all the Proof of Work of the next few blocks before anyone manages to do one (so that nobody can tell the difference).



As doing the Proof of Work of each block is extremely time consuming, there is a very small possibility of David redoing and finishing the PoW in time. In the end, David is caught red-handed.

From this scenario, we can, therefore, conclude that the Proof of Work system is vital as it minimises the likelihood of successful unauthorised changes within the blockchain.

ENSURING VALID TRANSACTIONS

It was briefly mentioned that transactions are broadcast into the Bitcoin network. But how can we ensure that no fraudulent transactions occur within the blockchain?

Digital signatures are therefore implemented; similar to hand-written signatures, digital signatures act as verification from the deal initiator to show that they have approved of this transaction.

However, to prevent forgery of signatures, the scheme of private key and public key are borrowed from cryptography.

Private key ensures that every signature is authentic and unpredictable. As the name suggests, it is only accessible to the deal initiator. A function is used such that it outputs a signature:

Sign

(Transaction Information, Private Key) — Signature

The deal initiator has to use that signature to make the transaction valid. Once the transaction is confirmed, it is then sent into the Bitcoin network. The Miners then have to check if the transaction is authorised, which is a process that involves another function:

Verify

(Transaction Information, Signature, Public Key) — True/False

An output of 'True' indicates that the signature is correct and therefore authorised. The Miner can then move on and include this transaction into their block.

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How the Curriculum Destroys Maths

by James Yuen, Lower Sixth, Harrow School, London

How the Curriculum Destroys Maths

"Which month has 28 days?" "All months have 28 days." Believe it or not, mathematicians are picky in words. If the question was "which month has exactly 28 days", we would indeed answer February as a normal human being would. However, just to contradict myself today, I am going to talk about how the abundance of words has caused deterioration in the maths education system around the world. Since maths has been developed a lot from the natural numbers, we do not have the ability to derive formulas and theorems fluently from first principles. Blame the school, and blame maths A-level if the only thing you remember ten years later in life about maths is entering numbers into your calculator.

Two types of maths structure our A-level course: computation and application, which sparingly corresponds to pure maths and applied maths. The computation strand is very easy to learn, and definitely the easiest to forget, as it is basically a mundane process once you get the gist of it. The application strand, though, requires more brain. Adapting to different situations is key, and often this is the part which lets maths students down. Let's say a child throws a tennis ball in projectile motion. As a diligent maths student (I claim to be), it takes no time for me to put down the equations and solve for whatever variable required. But stop right there. Does this model correspond to what is in real life? One of the most irritating facts about maths in school is how they always put you into such a perfect world. No one ever thinks about the sources of error, with air resistance being the obvious one. Let's have a look at a question here, from a textbook which I shall not name and shame:

'A 7 kg bowling ball moves at 3 m/s. How much kinetic energy does the bowling ball have?'

How boring. A simple formula does the job. Would we always have all the information we need to solve a real-life problem though?

It is the naiveness of these questions which leads the downfall of our own ability to find out about maths. We get fed – I say that having experienced years of maths education from some of the top colleges around the world. Not long ago I encountered a video about types of students bad at maths. The lack of initiative was emphasised in the video. Every time we step into a maths lesson, teachers start showing off their maths skills on the whiteboard and demonstrating rigid methods for problems. Then, students lack retention. Not many are able to watch and learn immediately. For maths, always do it yourself repetitively. It gives you a chance to get shouted at for suspected doodling in lessons. My point here can be easily proven if you hand out GCSE math exams to a random sample of people in the public, not many will be able to pass, miserably.

Back to the question about kinetic energy, it does not present any beauty of maths. Grinding through these questions may have redirected potential mathematicians to complete a Physics degree (an inferior maths degree) instead. Undeniably these basic questions help students who are less capable in numbers, but I am sure they would not be interested in pursuing a maths career anyway. It is an unfortunate fact that teachers are selling a product that weaker students by law are forced to buy. Exam boards may have been aware of this, since the abler among us must have been yawning about these mundane questions. The separate subject, Further Maths, as they call it, was no improvement at all. It has more maths (as its name suggests) – but no improvement of style of questions. If you aren't a mathematician and still haven't left, congratulations, a GCSE question is coming up:

'A water tank is in the form of a regular octagonal prism. The base octagon has side length 11.9 cm. The lateral edge of the water tank is 36 cm.

a. What is the surface area of the base?
b. What is the volume of the water tank?
c. If you pour water into the tank at a rate of 1.8 cm3/s, how long will it take you to fill the tank?'

(P.S. please read on regardless of your ability to solve the question above)

Having mentioned about the poor style of questions, shall we discuss how a question like this can be improved. Be prepared, mathematicians, you may disagree with what I think is still a maths question. An obvious place to start would be eliminating the subquestions. They really guide you too much to the final answer, which transforms the question into brainless bookwork for the scrimshankers. The second thing to do would be eliminating all the details, i.e. the description of shape and precise numbers. They mislead you into paying too much attention to the final numerical answer. So, an ideal question would be 'How long will it take you to fill a tank?'

Resist your temptations to say I am not a mathematician. If a mathematically talented person talks about this question, it must be the case that a mathematically untalented person can join the discussion without the fear of numbers flying around. In this question, it is essential to think about what matters. Does the volume matter? Does the rate of filling the tank matter? Or does the colour of the tank matter? Now that all students of different ability are on even ground, I am sure maths may well become the most favourable subject of all.

To conclude, the root of the problem in maths education is the 'helpfulness' of the questions. Always ask the shortest question you can and leave the rest to the students. The intuition of students will direct them correctly to approach a question. Make sure we try to eliminate questions which are for crying out loud, although we will still be stuck with the numbers in maths!

Fermat's Last Theorem

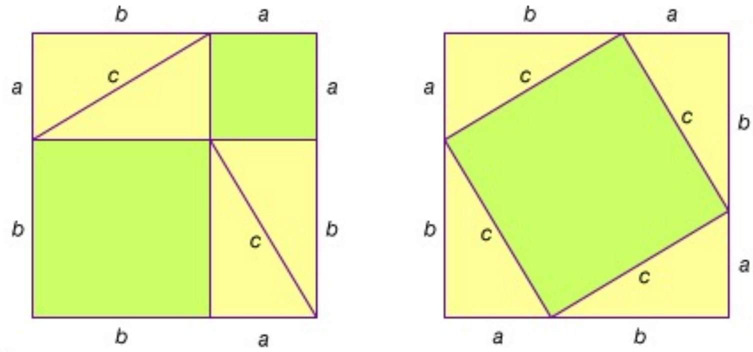
by Amy Siripoonya, Lower Sixth, Harrow International School, Bangkok

You may be familiar with Pythagoras' Theorem. This simple yet significant theorem is a staple in secondary education around the world and often your best friend when it comes to geometry problems.

Pythagoras' Theorem:
In a right-angled triangle, the square of the hypotenuse is equal to the sum of the squares of the other two sides.

$$a^2 + b^2 = c^2$$

This simple theorem is backed up with many simple and elegant proofs easily understandable by anyone who can understand the theorem itself. This is exemplified by this rearrangement proof:



See how the yellow areas in the first diagram can be rearranged to form the second diagram and how this proves Pythagoras' Theorem.
Now, there are some integers that satisfy Pythagoras' Theorem. These are referred to as Pythagorean Triples and there is an infinite amount of them (Why?). Some small examples include (3,4,5), (5,12,13) and (8,15,17).

Finding Pythagorean Triples is an example of solving a Diophantine equation – equations which have positive integer solutions for all variables. Unsurprisingly, Diophantine equations are named after Diophantus who developed methods for solving such equations. Looking at Pythagoras' Theorem leads us to consider other similar Diophantine equations such as what if we replace the power of 2 with another integer, perhaps 3. Would there still be positive integer solutions? The somewhat surprising answer is no. $x^3 + y^3 = z^3$ has no integer solutions. Of course, there is a proof for this however it is much too long to fit into this article.

If you are interested, you may wish to Google this yourself. This brings us to a more general case: For which positive integer values of n does $x^n + y^n = z^n$ have positive integer solutions?

And thus, Fermat's Last Theorem states:

$$x^n + y^n = z^n$$
$$n>2$$
$$x,y,z \neq 0$$

Has no positive integer solutions.

Pierre de Fermat was a French lawyer and "amateur" (I say this as Maths was his hobby, not his profession) mathematician living in the 17th century. Fermat was known to be cheeky and very secretive about his proofs. He would send letters containing theorems to other mathematicians claiming that he had proved them and challenging the recipient to do so as well. Fermat's Last Theorem was first discovered scribbled into the margin of a copy of Arithmetica (by Diophantus). In that margin, Fermat claimed that he had proved the theorem, but the margin was too small to include the proof. After much searching, Fermat's proof was never found. Thus, a three-hundred-year race to prove one of mathematics' greatest mysteries began.

The labelling of Fermat's Last Theorem as a theorem rather than a conjecture before it was officially proven was quite controversial. A mathematical statement is only a theorem if it has been proven. However, this was defended by saying that Fermat had actually proved the theorem – the proof is just unknown by everyone else.

Over the years, many incentives have been created for proving Fermat's Last Theorem. The French Academy of Sciences offered prizes in 1816 and 1850. The Academy of Brussels offered a prize in 1883. The Göttingen Academy of Sciences offered a prize of 100,000 gold marks in 1908 courtesy of Paul Wolfskehl. Despite the multitude of prizes, the greatest incentive of all in proving Fermat's Last Theorem was the prestige and honour of proving something that stumped some of the best mathematical minds ever to have lived.

Initially, mathematicians tried to prove specific cases of Fermat's Last Theorem. Fermat himself proved the special case $n = 4$ and established that if the theorem is true for a given prime number then it is true for any number divisible by that prime. By 1839, after two hundred years, the theorem had only been proven for the primes 3, 5 and 7, mostly attributed to a breakthrough by Sophie Germain. The next breakthrough was in 1850: Ernst Kummer proved that Fermat's Last Theorem was true for all regular primes. Unfortunately, the definition of a regular prime is too complicated to include in this article, but it is conjectured (but not proven) that at least half of all primes are regular. By 1993, the theorem was proven for all primes less than four million with the help of computers.

When the next big breakthrough occurred, it was in a seemingly unrelated field. In 1955, Goro Shimura and Yutaka Taniyama conjectured that there may be a link between two completely unrelated branches of mathematics: elliptic curves and modular forms. This became known as the Taniyama-Shimura conjecture. At the time, many mathematicians considered this conjecture impossible to prove. In 1984, Gerhard Frey suggested that there was a link between the Taniyama-Shimura conjecture and Fermat's Last Theorem. This link was proved by Ken Ribet in 1986.

Now, all one had to do was prove the Taniyama-Shimura conjecture to prove that Fermat's Last Theorem was true, which is exactly what Andrew Wiles did.

Andrew Wiles is a British mathematician who had previously worked on elliptic curves and had been fascinated by Fermat's Last Theorem since he was ten years old. Wiles spent six years secretly working on the proof of Fermat's Last Theorem. He finally presented his work in a series of lectures in 1993. This was obviously huge news in the mathematical world. However, before the proof was to be accepted, it had to be thoroughly reviewed. Many mathematicians picked up on a critical error in the proof. Wiles worked on the proof for another year before finally being able to correct the mistake and publish his proof in 1994.

Wiles's proof is incredibly complex so naturally it will not be included in this article. Since the mathematics used was much more advanced than anything that existed during Fermat's time, many speculate that Fermat didn't actually have a valid proof. Whether he purposely fooled everyone or whether he actually believed that he had a proof is up for debate.

For his efforts, Wiles was awarded a plethora of accolades including a special prize from the International Mathematical Union (in the place of a Fields Medal due to Wiles being over the age limit) and an offer to model for the Gap (which he declined).

Though Fermat's Last Theorem may be pretty insignificant to our everyday lives, it is a demonstration of how mathematics has grown in the 358 years between its posing and its proof.

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Fermat's Last Theorem, Simon Singh – If you were intrigued by this article, I highly recommend that you read this.

To the world of Polyhedrons

The mathematical figure of perfect beauty

by Wendy Chang, Year 11, Harrow International School, Bangkok

DEFINITION OF A REGULAR POLYHEDRON

To be classified as a regular polyhedron, there are two main properties that a three dimensional convex object should follow:

1. All faces should be congruent regular polygons
2. Same number of faces should be arranged all alike around each vertex

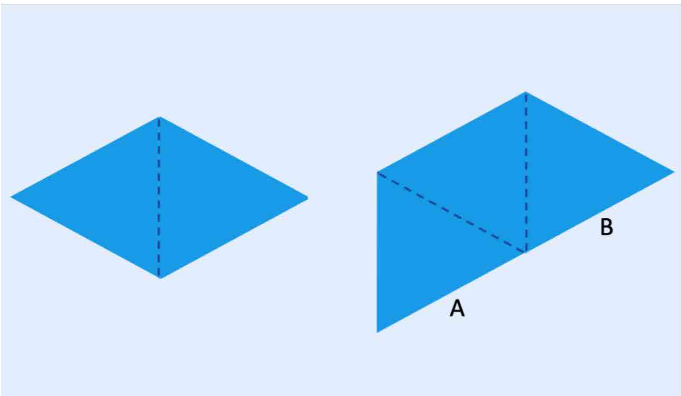
One interesting fact is that there are only FIVE regular polyhedrons in the entire universe. Only FIVE?! But why? There are an infinite number of regular polygons that can possibly be the faces. Let's get to the bottom of the secret.

For a better understanding, we will use planar figures.

To form a 3D object, there must be more than two faces that meet at one vertex. (*)

The first geometric figure has two equilateral triangles gathered at one vertex. No matter what you try, this shape remains on the plane.

However, in the second figure, there are three equilateral triangles gathered at one vertex. When you meet two sides A and B, a 3D shape pops out!



Planar figures

1. *Two equilateral triangles gathered at one vertex*
2. *Three equilateral triangles gathered at one vertex*

DIFFERENT TYPES OF REGULAR POLYHEDRONS

To make sure we do not miss out anything, we will classify the objects by the shape of regular polygons used as faces.

1) Equilateral triangle [single angle size = 180°/3 = 60°]

(i) When three equilateral triangles meet at one vertex: (begin with three*)
Total angle gathered at one vertex: 60° x 3 = 180°
180° < 360°, so can be a 3D object [Tetrahedron]

(ii) When four equilateral triangles meet at one vertex:
Total angle gathered at one vertex: 60° x 4 = 240°
240° < 360°, so can be a 3D object [Octahedron]

(iii) When five equilateral triangles meet at one vertex:
Total angle gathered at one vertex: 60° x 5 = 300°
300° < 360°, so can be a 3D object [Icosahedron]

(iv) When six equilateral triangles meet at one vertex:
Total angle gathered at one vertex: 60° x 6 = 360°
As the total angle is not below 360°, it can not be a 3D object.
Therefore, the maximum number of equilateral triangle shaped faces that can gather at one vertex is five.

2) Square [single angle size = 360°/4 = 90°]

(i) When three squares meet at one vertex:
Total angle gathered at one vertex: 90° x 3 = 270°
270° < 360°, so can be a 3D object [Cube]

(ii) When four squares meet at one vertex:
Total angle gathered at one vertex: 90° x 4 = 360°
As the total angle is not below 360°, it can not be a 3D object.
Therefore, the maximum number of square shaped faces that can gather at one vertex is three.

3) Regular pentagon [single angle size = 540°/5 = 108°]

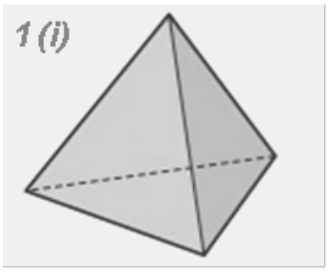
(i) When three regular pentagons meet at one vertex:
Total angle gathered at one vertex: 108° x 3 = 324°
324° < 360°, so can be a 3D object [Dodecahedron]

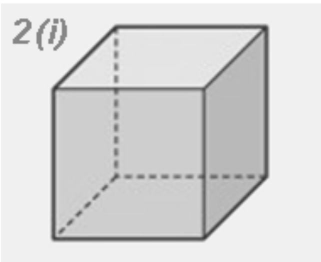
(ii) When four regular pentagons meet at one vertex:
Total angle gathered at one vertex: 108° x 4 = 432°
432° > 360°
As the total angle is over 360°, it cannot be a 3D object.
Therefore, the maximum number of regular pentagon shaped faces that can gather at one vertex is three.

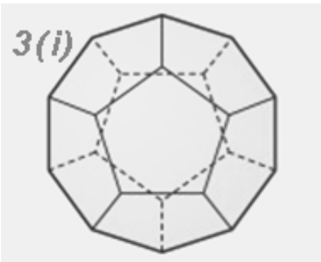
4) Regular hexagon [single angle size = 720°/6 = 120°]

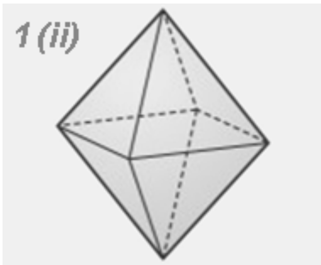
(i) When three regular hexagons meet at one vertex:
Total angle gathered at one vertex: 120° x 3 = 360°
As the total angle is not below 360°, it can not be a 3D object.
Therefore, regular polyhedra can no longer be made from regular hexagons and other regular polygons with more sides than six.

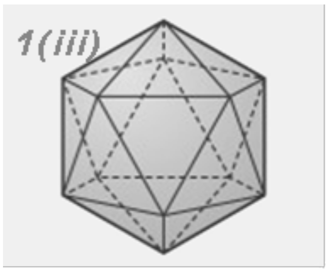
In total, only five regular polyhedrons exist:
Tetrahedron, Cube, Octahedron, Dodecahedron, and Icosahedron











From the top, in order Tetrahedron, Cube, Octahedron, Dodecahedron, and Icosahedron

REGULAR POLYHEDRONS, HISTORY, AND ART

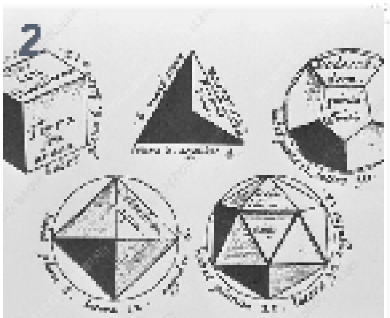
Ancient people found regular polyhedra with both balance and stability very attractive. Its uniqueness inspired Plato, that in his own philosophy, he used them as a symbol of the five basic elements: fire, earth, air, water, and the universe. (2)

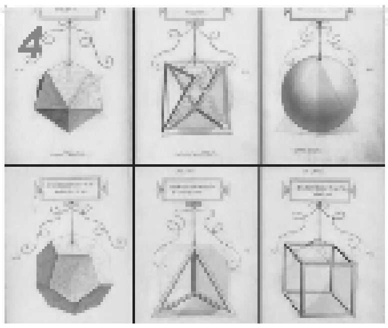
The Romans used regular polyhedrons as dice, including the cube, a common shape used these days. Since each face has the same shape and area, it works as a dice allowing equal probabilities when rolled. (3)

Regular polyhedra often appear in works of art. For example, the 'Portrait of Luca Pacioli' by the Italian painter Jacopo de' Barbari depicts a dodecahedron. (1)

Leonardo da Vinci also drew the skeletal shape of a regular polyhedron. (4)

It is not only a mathematical figure but also a unique artistic model. Why not explore the attractiveness of regular polyhedrons? The more you know, the more you will be amazed!

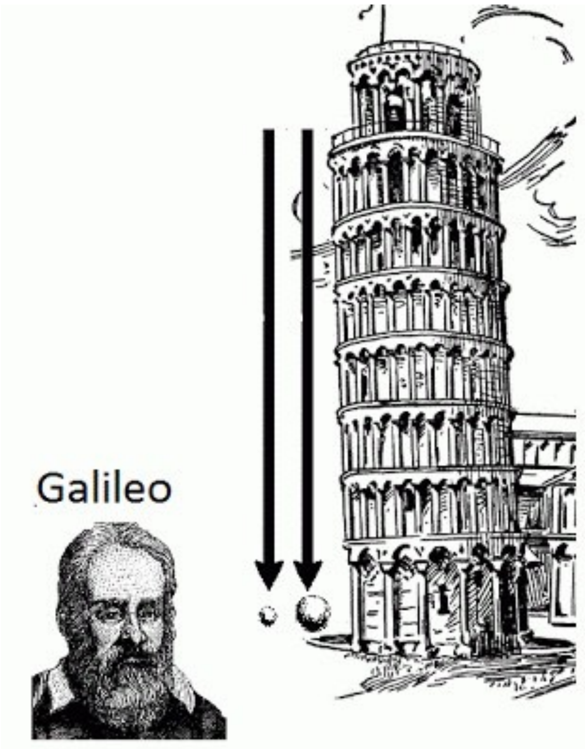




Relativity: space and time

by Moni Tojirakarn, Year 11, Harrow International School, Bangkok

Galilean principle of relativity



If we trace back in time to find how the theory of relativity originated, we would arrive at the ideas of motions of bodies, developed by Galileo and Newton.

Before them, people believed that the natural state of a body was to be at rest and that it can only be moved by a force or impulse as proclaimed by Aristotle. Moreover, it was said that a heavier body will fall faster due to it having a greater pull toward the Earth.

However, Aristotle's beliefs were proven wrong as Galileo set up an experiment by rolling balls of different weights down a smooth slope and measuring their acceleration. The result of his experiment demonstrated that the acceleration of all bodies was the same despite their weights. Thus, the reason some objects fall vertically slower than others is because they are more affected by air resistance, slowing them down.

Galileo's theory was then confirmed by David R. Scott who performed an experiment of dropping a feather and a hammer at the same time on the moon. With no air to slow the objects down, both the feather and hammer indeed hit the ground at the same time.

Newtonian mechanics

Galileo's experiment demonstrated how the real effect of a force is to change the speed of an object rather than just to set it moving. Newton then used the results supported by these experiments to develop his three laws of motion.

The Galilean principle of relativity also states that Newtonian mechanics are always the same in any inertial reference frame, regardless of whether the observer is at rest or moving at a constant velocity. Here, Newton's laws illustrate a great discovery that there is no absolute standard of rest.

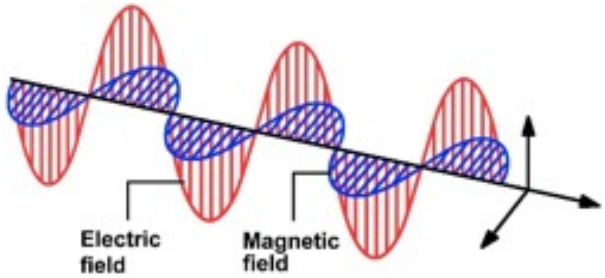
Consider the Earth, for example. The Earth itself cannot be regarded as an absolute frame of reference because it is always moving in relation to other objects in the universe, resulting in a perceived motion. In other words, Newton's laws show how one can equally say that the Earth was at rest while a truck was moving at a constant speed in respect to it, or that the truck was at rest and the Earth was moving. As Newton's laws would still hold if an experiment was carried out on the truck or on the ground, it is impossible to ascertain whether it is the truck or the Earth that is moving.

Consequently, the lack of an absolute standard of rest means that an absolute position in space for an event cannot be determined. For example, imagine a person (A) tossing a ball vertically upward whilst standing on a moving train and another person (B) also observing the motion of the ball but on the sidetrack. To person A, the ball would've just bounced up and down on the same spot. However, to person B, the ball would've appeared to move around 5m horizontally (depending on how far the train has traveled) before landing back onto person A's hand.

Another law that Newton discovered which played a significant role in the field of relativity is one that describes the force of gravity, stating that "every particle attracts every other particle in the universe with a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between their centers".

Nonetheless, as the discovery of the speed of light uncovered, Newtonian mechanics lack the full explanations to support it. This was due to the fact that Newtonian mechanics assume that time is absolute, also leading to a misconception of what "gravity" is.

Speed of light



Even though the fact that light travels at a finite speed was proven in 1676 by Ole Christensen Roemer, the proper theory of the propagation of light was only just discovered in 1864 by James Clerk Maxwell.

Maxwell's theory identifies that electric and magnetic forces are not separate, but are both manifestations of electromagnetic force; their oscillations form EM waves. Hence, Maxwell concludes that light is an EM wave with such wavelengths that can be detected by the eye. In addition to this, Maxwell then formulates an equation which determines the speed of light.

Nevertheless, conflict arises as the idea of fixed speed of light contradicts Newton's theory that there is no absolute rest. Moreover, the constant speed of light gives light its simultaneity property which leads to a simultaneity mismatch that cannot be explained by Newtonian mechanics.

Unresolved questions that couldn't be explained by Newton's law resulted in scientists attempting to find a proper explanation. Therefore, it was suggested that light waves should travel through and be relative to the "ether", a substance that is present everywhere, even in "empty" space.

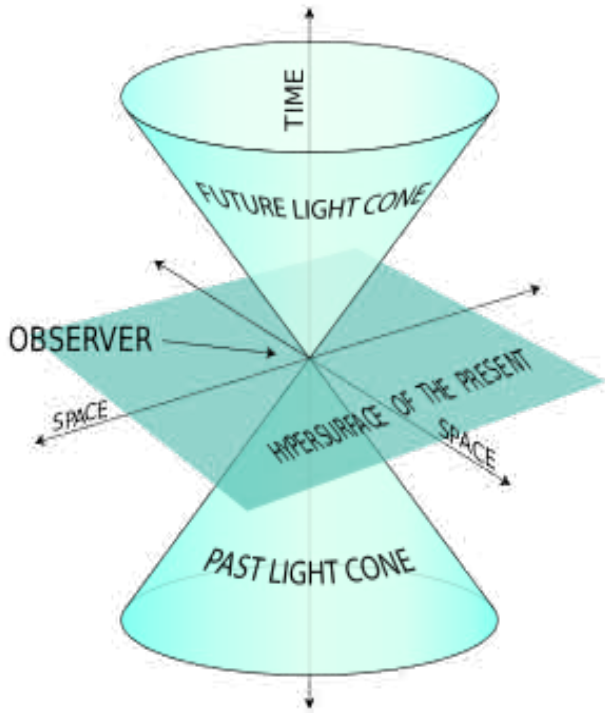
Since the Earth is constantly changing its motion by orbiting around the Sun, the Earth is also moving relative to ether. This means that even though the speed of light is constant, the speed of light measured on Earth would be the sum of the speed of light and the speed of ether wind.

Consequently, the results should differ depending on where we measure it: it should be higher in the direction of the Earth's motion through the ether than at right angles to the motion. However, astonishingly, all their measurements were exactly the same meaning the "ether wind push" wasn't detected!

Einstein's discoveries

Eventually, these problems were solved as Einstein initiated the theory of relativity into the world of Physics, putting an end to the idea of absolute time. He extended Newtonian mechanics with Maxwell theory, proposing that all observers should measure the same speed of light, no matter how fast they're moving, (the speed of light), and the law that nothing travels faster than the speed of light. Einstein then develops many new theories using this simple idea. Perhaps the most well known ones are the equivalence of mass and energy (E = mc^2 where E is energy, m is mass and c is the speed of light. Thus, an object can never reach the speed of light as its mass would have to become infinite and so would the energy required for it to get there.

In relativity, all observers must agree on how fast light travels, while bearing in mind that time and space are not absolute.



Therefore, observers who are moving relative to each other will not agree to the times and positions of an event taking place.

In addition to this, the theory of relativity also puts an end to the idea that time and space are separated from each other.

Instead, they are relative and the theory of special relativity (a simplification of general relativity where the effects of gravity are ignored) illustrates how light spreads out from an event, forming a three-dimensional cone in the four-dimensional space-time.

As nothing travels faster than the speed of light, the path of any object through space and time must be represented by the line that lies within a light cone. Thus, the events in the future can only be affected by what happens at the present event.

However, the theory of special relativity is not compatible with the Newtonian theory of gravity as forces should change spontaneously if two objects move apart meaning that gravitational effects should travel at infinite velocity, not at or below the speed of light. Therefore, Einstein developed the theory of general relativity in 1915, suggesting that gravity is not a force but an effect of space-time being "curved" or "warped" by the distribution of mass and energy in it.

In general relativity, bodies always follow a geodesic, a straight line in curved, four-dimensional space-time. However, they appear to us to be moving along curved paths in our three-dimensional space. For example, in our solar system, the mass of the Sun curves space-time in such a way that even though the Earth is following a geodesic path in the 4D space-time, it appears to us to be orbiting around the Sun in a circular motion in our 3D space.

Both Newtonian mechanics and the theory of relativity are revolutionary discoveries which put an end to the idea of absolute time and space. Space and time are things which revolve around us as not only will they affect but also will be affected by everything that happens in our universe.

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Wikipedia for specific definitions
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The Beauty of Chaos

by Kevin Liew, Year 11, Harrow International School Hong Kong

As Albert Einstein once proclaimed: "As far as the laws of mathematics refer to reality, they are not certain, and as far as they are certain, they do not refer to reality". At its core, chaos theory is an intricate science revolving around nonlinear processes that are fundamentally impossible to predict or control, ranging from the weather and our brain states, to stock markets and earthquakes. From the beating of a heart to the drift of planets across the starry skies, chaos is ever-present in our world. But how can such a vast, unpredictable, and uncontrollable concept like chaos be expressed in a numerical format? And how can we adapt to its ever-growing prominence within our society?

From a Butterfly to a Hurricane

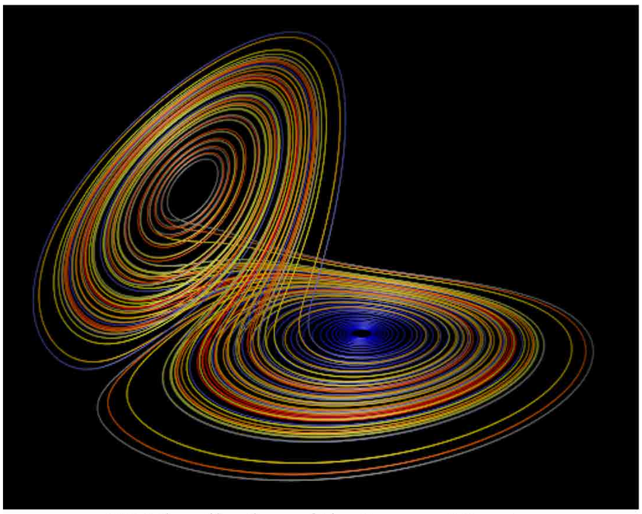
In 1961, an MIT meteorologist professor by the name of Edward Lorenz came across this startling revelation. Lorenz developed a mathematical model which enabled him to simulate weather patterns a few minutes in advance by employing the use of numerical values which represented the current weather. One day, he repeated an earlier simulation that he ran before, except instead of taking the exact value of one of the variables, he rounded one of the variables from .506127 to .506. Through this small difference, Lorenz had inadvertently discovered the mathematical incarnation of chaos.

Although, at first, both values produced identical products, they slowly diverged from each other, producing radically different results increasing in size and scale until it became incalculable. This phenomenon of a simple, deterministic equation being able to produce various different outcomes given small changes in the input value was labelled as "deterministic chaos", more infamously known as the "butterfly effect"[1]. In short, seemingly insignificant disturbances in the atmosphere can build up over time towards an unanticipated drastic outcome.

Chaotic systems, like the weather, are generally sensitive to initial conditions as its output values drastically differ depending on the input values. There are multiple nonlinear parameters within these chaotic systems that have to be accounted for, making it hard to predict the end result. One notable model of deterministic chaos is the pinball machine, as even the smallest difference in its starting position and speed can potentially result in the pinball bouncing off different bumpers. Nothing is guaranteed, and there will never be two indistinguishable games.

Not only did Lorenz unintentionally make a major breakthrough in one of the most important mathematical concepts in shaping the world as we know it, but he also uncovered one of its key fundamentals. When attempting to graph his data over several axes, he came across a peculiar observation that for two nearby points undergoing the process of iteration, the line produced when connecting the points would grow increasingly apart from each other with each new iteration. However, for points away from the region of the line, they would eventually converge towards each other. This complex contradictory system is known as a "strange attractor", with Lorenz's unique dynamics being named after himself: the "Lorenz attractor".

Other strange attractors were discovered later, including the Hénon attractor in 1976, which all had self-similar structures as noted by French-Polish mathematician Benoit Mandelbrot. This will be explored in more depth later on, but for now, we should define what we mean by chaos in the mathematical sense.

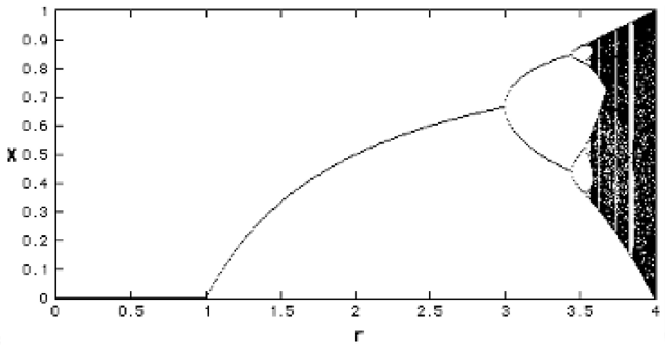


3D Visualisation of the Lorenz Attractor

[1] In an analogy for his findings, Lorenz stated that the flapping of a butterfly's wings in the Amazon could potentially in turn cause a hurricane or tornado in China. Without the butterfly flapping its wings at that specific spot in that precise time and space, that hurricane would not exist in the future.

A Map to Fractals

One of the most common examples of the chaos theory is the logistic map, a discrete iterative mathematical function popularised by mathematical biologist Robert May, that maps the population value at any point in time to its value at the subsequent point in time. This model can be represented as the equation: $x_{n+1} = r * x_n (1 - x_n)$, with r representing a rate of growth, x_n as the population for that specific year, and x_{n+1} being the population for the next year. It should also be noted that the population (x) is being expressed as a fraction between 0 and 1, with 0 representing extinction, and 1 being the maximum possible population.



Bifurcation Graph of the Logistic Map

It can be determined that for any population, only after enduring many fluctuations of varying degrees will it reach a stage of equilibrium. If we visualise this set of data as a bifurcation diagram, we notice that though at the beginning for smaller values of r there is only one line, for larger values, it can break up into several lines and become completely chaotic.

It can be noticed that for smaller values of r between 0 and 1, the population cascades towards the state of extinction, whereas for larger values of r between 1 and 3, the population may converge towards a single value. For values of r greater than 3, the graph bifurcates (breaks into two different lines) due to the population now fluctuating between two possible values. For larger values of r, the bifurcation intensifies and multiple bifurcations lead to the graph becoming more chaotic and unpredictable in its essence. However, there are certain brief periods of "order" at the onset of chaos, where the points become predictable. After a period of chaos, these abruptly disappear for a brief moment, before doubling and becoming more chaotic in an endless perpetual cycle. The mathematician Mitchell Feigenbaum concluded that this property of scaling was crucial to unlocking the mysteries regarding such perplexing systems, which could also be applied to other nonlinear systems in the real world.

The chaotic part of the graph can be labelled as a fractal, which is an infinitely complex pattern that is self-similar throughout different scales. Fractals follow the trends of chaotic behaviour, enabling us to express a vast range of dynamical systems as physical manifestations of chaos. It is materialised in our world through various forms, such as the identically-shaped leaves on trees and ferns, the branching tributaries in river deltas, and the shapes of mountain ranges.

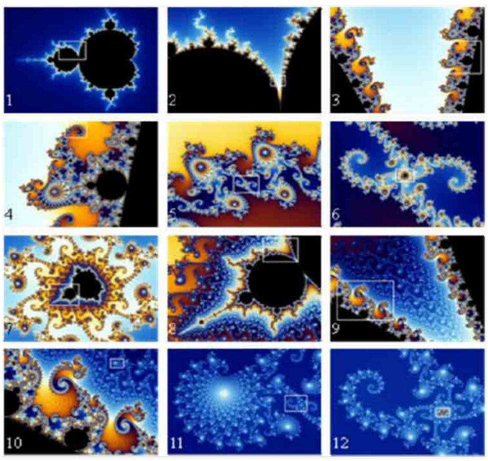
An infamous fractal known as the Barnsley Fern

The Thumbprint of God

Referred to by some as "The Thumbprint of God", the Mandelbrot set (named after the mathematician Benoit Mandelbrot) is among the most stunning projections of mathematics in its purest form. Constructed from a two-dimensional complex number plane, it follows the equation: $Z_n = (Z_{n-1})^2 + C$, with C being a complex number. Let's begin with the assumption that $n - 1 = 0$, at which point the equation then becomes $Z_1 = (Z_0)^2 + C$. When iterating the equation, you will find that $Z_{n+1} = (Z_n)^2 + C$. If the results get infinitely larger for a specified value of C, then it can be determined that the given value of point C (on the complex number plane) is not part of the Mandelbrot set. Conversely, if the output values follow a repeating pattern and do not increase further by each step, the point C does lie within the set. For example, at C = -1, the results will follow the order of 0 and -1, therefore -1 is a point within the Mandelbrot set. At C = -2, Z_1 would be equal to -2, and every iteration after would constantly loop with the end result of 2, so this point also lies in the set. However, at C = 1, the result will increase infinitely, so this is not part of the set. After doing this with every possible point on the complex plane, a Mandelbrot set would be created.

The Mandelbrot set contains an endless number of sublime repeating patterns (which may be identical to the Mandelbrot set itself, but never an exact replicate) that can be explored by zooming into different parts. Theoretically, any pattern can be generated from this set as long as you magnify the right area. One mathematician by the name of Roger Penrose stated that the Mandelbrot set is evidence for mathematical realism; essentially stating that the set is so complex that it could not possibly have been invented, but only discovered.

There is a spiritual beauty to the Mandelbrot set in that it is a reflection of the abundance of self-similar fractals ubiquitous in our atmosphere, to the point where some theorise that the universe itself is an autogenic fractal and that any existing object can be mathematically generated. It's infamous for proving that a simple set of instructions is capable of producing infinitely complicated, and at certain points, chaotic results. In Mandelbrot's words, this feedback loop exhibits "profound connections between fractal geometry and chaos theory".



Zoomed in images of the Mandelbrot set

Our World in Chaos

As cyberspace progressively evolved from a localised monolithic structure to a more globalised wireless format through the emergence of more complex technologies, system failures have become harder to notice in advance. In order to improve the resilience of modern computer systems against such failures, engineers have relied upon an empirical method known as chaos engineering. Based on the concepts of chaos theory, this practice studies the ability of computer systems to adapt and respond to potential random, unplanned issues that could propagate to catastrophic shutdowns. Instead of dreading the inevitable chaos, this allows us to simulate it ourselves within a controlled environment to build resilience and durability in the application to withstand such turbulent conditions. We can gain further insight into potential outages, locate the faults within the system, and make improvements.

This form of resilience testing was pioneered by none other than the content streaming giant, Netflix, whose engineering team created a sandbox for chaos testing after transitioning to an Amazon Web Services (AWS) infrastructure. This migration to the public cloud led to challenges of the service nodes randomly terminating, resulting in a hindered customer experience due to slower streams with lower quality. To prevent this, they created the tool 'Chaos Monkey', which would induce host failure by randomly disabling nodes in the production network that stored the whole platform's inventory of films and TV shows. This later developed into a wide suite of failure-inducing tools, collectively known as the Simian Army. Each troop covers different failure types, such as Security Monkey which inspects the system for potential vulnerabilities, Latency Monkey which replicates service unavailability, and Chaos Kong which recreates an entire regional outage. Netflix further built upon these foundations in October 2014, with the introduction of Failure Injection Testing (FIT) which protects customers from the impacts of chaotic experiments by supplying metadata that specifies the limits of a certain test, controlling the amount of failure testing that is allowed to occur.

In this new era of system integration, chaos engineering helps to build the defensive capabilities of systems and reduce the number of outages that occur whilst refining customer experience. From a business perspective, it also helps to prevent revenue losses from unexpected server downtime which, according to a June 2020 study, could cost between $1-5 million per hour for around 40% of enterprise organisations. In light of this, an ever-rising number of enterprises are starting to recognise the value of this approach and implement it into their software, such as Uber, Facebook, and Google. Unlike any other variants of failure testing, chaos engineering enables a system to explore uncharted territory and navigate its way around a diverse scope of complex real-world issues.

Chaos theory has several other real-world applications, such as compressing digital data into smaller sets which can later be enlarged and reconstructed utilizing computer algorithms (like ZIP files). Investors may employ chaotic analysis to predict fluctuations in the stock market and avoid sudden stock market crashes. Generating computer artwork through the use of chaos and fractals displayed in a simple formula allows animators to easily draw numerous distinct trees by using its infinite range of products. It can also help physiologists comprehend the abnormality ventricular fibrillation as the byproduct of disorder in the chaotic system of the heart, or enable them to detect cancerous cells and bone fractures early on by noticing the fractal elements on their surfaces.

Conclusion

Overall, chaos theory brings scholars from several different fields together to study the impact of chaotic behaviour on our daily lives. At word level, the term "chaos" may insinuate randomness, unpredictability, and danger. However, upon closer inspection, we can begin to notice the precision and grace with which it has constructed, and continues to construct, the fabric of all natural phenomena. It informs the way we view deterministic systems — their seemingly irregular states of disorder are actually governed by a fundamental set of patterns. It has been proven that even with the most advanced technology, we can never fully guarantee an accurate forecast of what is to come. However, accepting traces of irregularity within order as a whole can be used to our benefit. For example, incorporating chaotic behaviour within weather forecast models can lead to more reliable forecasts. It serves as a reminder that ironically, through embracing chaos, we find a world of order with endless possibilities.

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Physical Sunscreens

by Jasmine Chan, Upper Sixth, Harrow International School, Hong Kong

INTRODUCTION TO SUNSCREENS

Sunscreen, commonly known as sunblock, is a substance that can absorb or reflect ultraviolet (UV) radiation from the sun on the skin that is exposed to sunlight. It can be in the form of a lotion, spray or gel which helps to protect the skin against sunburn. [1] They work by absorbing UV radiation into heat, [2] helping to reduce the risk of skin cancer, skin ageing, and sunburns. [3] In this article, I will be looking into a specific type of sunscreen - physical sunscreens.

PHYSICAL SUNSCREENS

Physical sunscreens are commonly inorganic substances that sit on top of the skin after application and can reflect or scatter UV light. This includes chemicals such as zinc oxide (ZnO) and titanium dioxide (TiO_2). These chemicals in sunscreen are 1/20th smaller than conventional pigments, known as microfine pigments. They are then dispersed and spread evenly into a base. Combinations of these chemicals with other substances can potentially reduce UV transmission, which means that it provides good protection for the skin against UVA and some wavelengths of UVB. Both titanium dioxide and zinc oxide can reflect and scatter UV and visible light and absorb UV light. [4] These chemicals are semiconductors (substances that conduct electricity under specific conditions) that can absorb light and generate reactive species, meaning that they are photocatalysts. [5, 6] They can promote the transformation of organic molecules when absorbing UV radiation. [6] When the photocatalyst absorbs UV radiation, it produces pairs of electrons and holes. The electron of the valence band (the band of electron orbitals that electrons can jump out of) of the photocatalyst becomes excited when illuminated with light, which promotes the electron to the conduction band (the band of electron orbital that electrons can jump up into from the valence when excited) of the photocatalyst. [7, 8, 9] The excitability of the chemical depends on its crystalline structure and the band gap - the difference in energy between the highest occupied energy state of the valence band and the lowest unoccupied state of the conduction band (See Fig.1). [4, 8] This creates pairs of negative electrons (e^-) and positive holes (h^+). A redox reaction then occurs (See Fig.2). The positive holes break water molecules, which forms hydrogen gas (H_2) and hydroxyl radicals (•OH) - this is the oxidation reaction. The negative electrons react with the oxygen molecule to form superoxide anions (O^{2-}•) - this is the reduction reaction. This photocatalyst cycle repeats once light is available. [7]

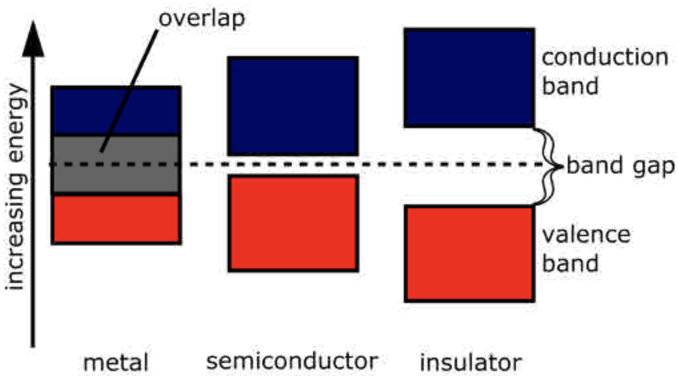

Fig.1 Visual Diagram of a Semiconductor and How it Differs from Metals and Insulators (Source: energyeducation.ca)

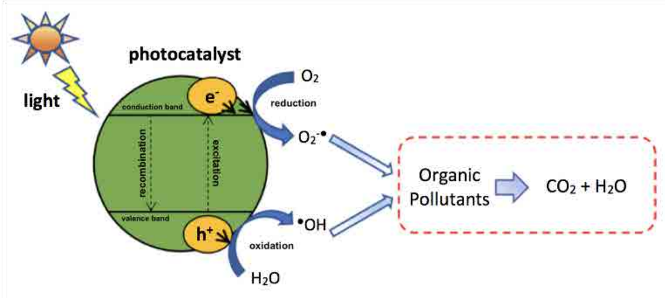

Fig.2 Visual Diagram of How a Photocatalyst Works (Source: nature.com)

PROPERTIES OF SUBSTANCES IN PHYSICAL SUNSCREENS

The ability of a substance to block light in physical sunscreens is determined by two physical properties: the substance's opacity and particle size. [4]

1. OPACITY

The opacity of a physical sunscreen is calculated by Snell's Law of Refraction (See Fig.3): Np sin i / Nm sin r where Np is the refractive index of the pigment in the physical sunscreen, Nm is the refractive index of the adjacent medium, which is air in this case, i is the angle of incidence (the angle between the incident light ray and the normal), and r is the angle of refraction (the angle between the emergent light ray and the normal). [10, 11]

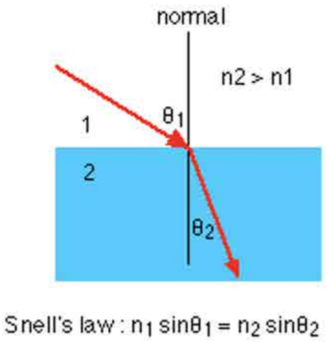

***Fig.3** Visual Diagram of Snell's Law of Refraction (Source: buphy.bu.edu)*

TiO_2 (rutile)	2.9	Magnesium oxide	1.7
TiO_2 (anatase)	2.7	Barium sulphate	1.6
Zirconium oxide	2.2	Mica	1.6
Yellow iron oxide	2.1	Talc	1.6
Zinc oxide	2.0	$CaCO_3$	1.5
Aluminum oxide	1.8	Fumed silica	1.5

***Fig.4** Table of Refractive Indexes of Different Inorganic Pigments (Source: [4])*

Refraction occurs when light meets a boundary between two media, and because there is a change in the refractive index (usually entering a medium with a higher refractive index), the velocity of light travelling in this new medium will be different (if the refractive index is higher, then velocity will decrease). Molecules with a high refractive index can increase the reflectiveness of the sunscreen. [4]

As the refractive index of the pigment increases, opacity increases since more light is scattered. [12] As the sunscreen is more opaque, the sunscreen has a white tint when applied to the face. This is known as white casting (See Fig.5).

***Fig.5** Examples of White Casting on Different Skin Tones (Source: labmuffin.com and naturallycurly.com)*

Nowadays, cosmetic chemists have incorporated more brown pigments in sunscreen such as iron oxide ($F_{e2}O_3$), which reduces the white-casting effect, making the sunscreen seem more natural on the face. This type of sunscreen is known as tinted sunscreen. The additional use of pigments can also enhance the scattering effect of the physical sunscreens, making the sunscreen more effective overall as different pigments have different relative opacities (See Fig.6). [4]

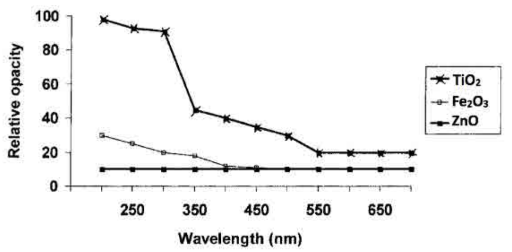

***Fig.6** Comparison of the Relative Opacities of Different Microfine Pigments (Source: [4])*

2. PARTICLE SIZE

The particle size of a pigment is the average size of the particles in the pigment. [13] The best pigments used in physical sunscreen are when the diameter of the particle is half of the wavelength of visible light. [4] One of the most common pigments used in physical sunscreen is titanium dioxide. As the size of titanium dioxide is relatively small (200-500nm in size), they generally have a greater ability to reflect light. [13] Despite particles being small, which can lead to transparency, the ability of the particle to reflect and scatter UV radiation is retained.

As the particle size varies, the type of scattering changes. In titanium dioxide, two types of scattering can occur, Mie scattering and Rayleigh scattering (See Fig.7). [4] For particle sizes larger than a wavelength of light, Mie scattering occurs, which is a type of scattering that produces a pattern similar to an antenna lobe. For larger particles, the antenna lobe like shape would have a sharper and more intense forward lobe. [14] For particle sizes around a tenth of the wavelength of light, Rayleigh scattering occurs where the patterns for forward and backward scattering are symmetrical. [15]

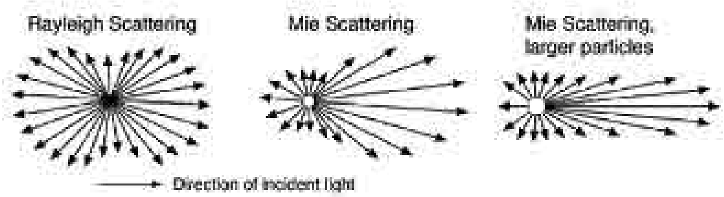

Fig.7 *Visual Diagram of Mie and Rayleigh Scattering (Source: [14])*

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Can the muons lead to a fifth force?

by Eric Zoica, Year 7, The John Lyon School, London

I am writing here about a very exciting development in the world of science. This could very well change how we understand physics and might change our understanding of the universe. I am talking about the Muon G-2 experiment. The experiment was originally done in Brookhaven but now the 2021 Fermilab is conducting it again and is getting close enough results to almost be named a discovery.

Fermilab smashed particles together to get the sub-atomic particle named the Muon. They can also be naturally found on the Earth's surface when cosmic rays hit the Earth's atmosphere. Muons are much like Electrons but there is one difference between them, the Muon's mass is almost 200 times bigger than that of an Electron. Fermilab then took these Muons and shot them through a magnetic field. They measured the spin of the Muons (how much they wobble) and there was something interesting there.

The Muons did not follow the Standard Model whilst in the magnetic field. The Standard Model is the 4 fundamental forces of the universe; Gravity, Electromagnetism, weak nuclear and strong nuclear, and all particles, Fermions and Bosons, interact with each other based on these rules. These can explain everything from why the sun is shining and why we stay on the earth, to why we exist. Using all our formulas and physics we still cannot figure out why the Muon behaves in this way. So, the only possible conclusion is that there is a fifth force at play here.

After repeating an experiment initially conducted about 20 years ago in Brookhaven, the scientists confirmed that the interaction between the spin of the Muon and the magnetic field is not within the expected limits – the G factor of the formula was expected to be just above 2, where in practice it was higher.

Scientists announced all of this on Wednesday the 7th of April 2021.

With all experiments, we have an expected range within which all results must fall. So, we have an expected range for theoretical results and an expected range for the experimental results. This range is called standard deviation or Sigma. For the results to qualify as a new discovery, the difference between the theoretical and experimental results needs to be 5 Sigma apart (1 in 3.5 million). Now there is a 1 in 40,000 chance that the experiment result is wrong - this is a 4.1 Sigma.

In order to push the results over the 5 Sigma doorway, we need to either repeat the experiment again till we get the 5 Sigma or we could improve the experiment in such a way that we can clarify the range which the results can fall into, making it 5 Sigma.

Now I just want to go through some of the many, many, many possibilities this can open for us.

- This can change space travel as we could use this fifth force to our advantage and find some sort of way to integrate this with our ships. This can help us travel faster than ever and we have only got to the moon so if we use this, we could be travelling to the edges of the galaxy in no time.
- We could use this fifth force to alter particles and manipulate them, like teleportation, shrinking or enlarging objects. We could even use this to make things (buildings, gadgets etc.) really quickly. I was thinking this could work like nanotechnology.
- We could use this information to understand dark matter/energy and we could begin to grasp the big bang and why it happened. It would help us immensely if we could control dark matter as this could be able to give unlimited power to the planet and our own households.
- We can use this to improve medicine, such as x-rays where we can make much more accurate pictures medical imaging and we can make new super microscopes which can look at even smaller things such as atoms and sub-atomic particles.
- We can use this to make much more sustainable cars, trains, motorbikes and other modes of transportation as we can use some sort of levitation to keep the car up and there will be no engine in the car. I was thinking something along the lines of how opposite magnets are in the car and in the road and the

transportation just slides off them and we can use the energy from this force to decrease the friction.

- As well as physics being rewritten this will have a massive impact on chemistry and will change how we understand the particle model and even all particles together. These new rules can be applied to agriculture, engineering, day to day life, the food industry and medicine.
- For transportation around the world, instead of toxic airplanes, we could use a ship that is the shape of the leaf, a boomerang. This new force could guide the ship wherever it needs to go (with the wind as well) and it will require no engine or toxic fuel of any kind. It will land safely on special landing pads around the world.

This new force can be world renowned and will probably change our lives forever. I can think of a million more way this could help us, but one problem stands out that NEEDS to be resolved. It increases by the moment and this is, of course, global warming and we need to do anything we can to stop it. This new force can help us to become more ecofriendly. But if things go over the edge we might need to colonise other planets and this force can help us harness the power for our ships to travel to far off "Goldilocks" planets.

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