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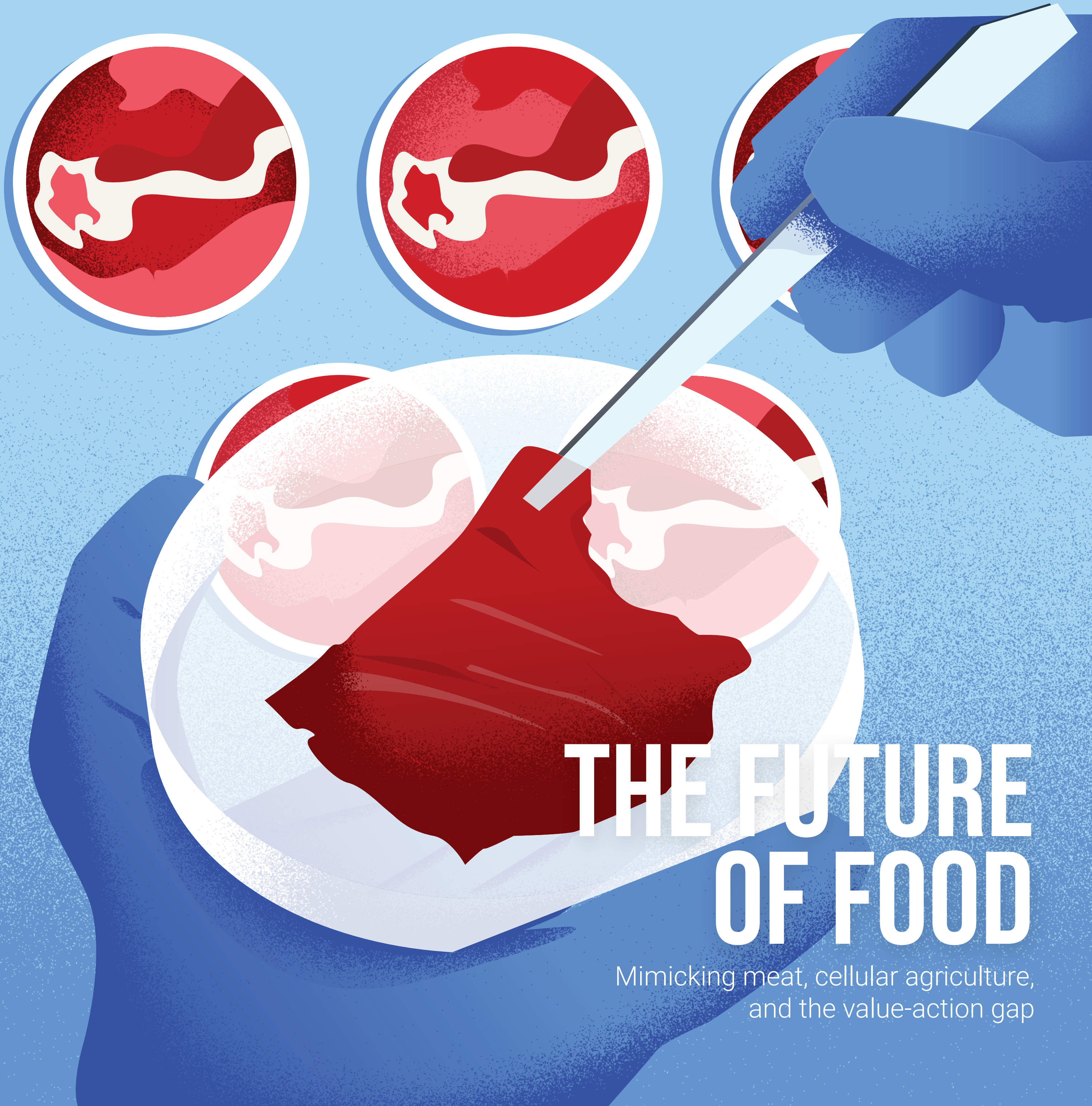

THE FUTURE OF FOOD

Mimicking meat, cellular agriculture, and the value-action gap

Editors' Note

Nau mai, haere mai! Welcome to the *Scientific*'s second issue of Volume Two.

As we jump back into on-campus life, we are all again adjusting into the routine of early wake-ups and watching lectures without the comfort of our pyjama pants. On-campus life does have its perks however; we were excited to see and talk to many of you at the science carnival and club expos within the first week back.

This issue will be the first released on campus since Issue Three, Volume One of 2021, and we are thrilled by the opportunity to finally see some of you at our launch events.

We feature plenty of amazing guest writers who span a range of disciplines and topics from the extra-terrestrial life hypothesis to the exploration of Einstein's miracles. Our cover article is an adaptation of a segment from 95bFM's show 'Tomorrow's World', written and produced by Isla Christensen, and Stella Huggins. Ella Spears uncovers the eusociality of honeybees that ultimately informs the roles and behaviours of individuals within a colony. Lucas Tan considers the potential for extra-terrestrial life, exploring a multitude of hypotheses that suggests why we are yet to encounter it. Detection of incognito plastics is developed by Nargiss Taleb and Eugene In as summer research interns in the use of Raman spectroscopic techniques. Lastly, Caleb Todd returns for his third instalment of the *Einstein's Year of Miracles* series, titled *Part 3: Relativity.*

As always, our own executive team has contributed fascinating content for this edition. Writing coordinator Sarah Moir explains the significance of bacteria and mosquito symbiosis in preventing and managing the Dengue burden. Lastly, our treasurer Alex Chapple reviews recent developments in the field of atomic clocks and continues to explain their benefits and more.

A big thank-you to our readers, and special thanks to our guest writers. We are continually amazed by the work and passion you all have for engaging and contributing to science communication — whether it be picking up the editions or writing a piece yourself.

Special thanks to Le En Loh from Ngee Ann Polytechnic Singapore for their amazing artwork that features on our cover page.

Ngā mihi maioha,
Sarah Moir, Writing coordinator for UoA Scientific 2022

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Einstein's third 'miracle year' paper redefined how we perceive the fabric of our reality.
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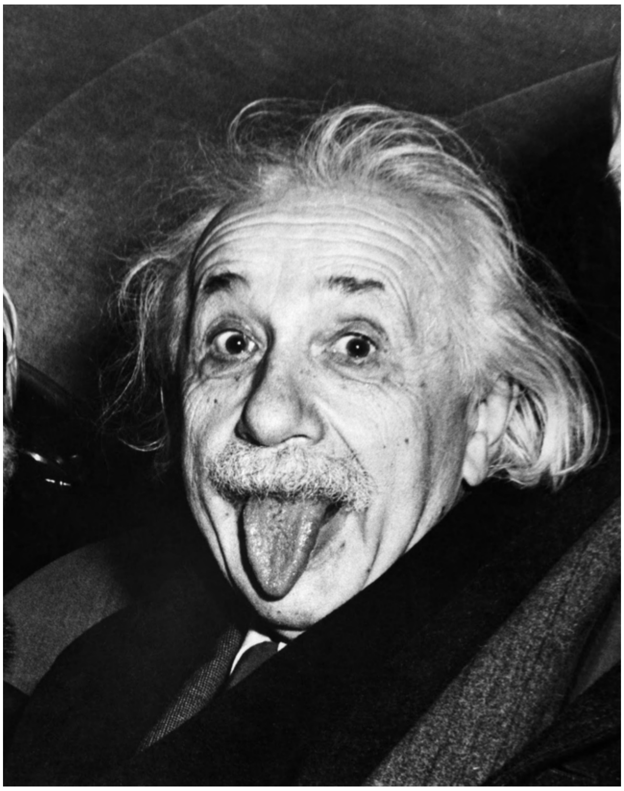


Figure 1: Albert Einstein, transcendent genius.

Einstein's theory of special relativity is among the greatest scientific works ever produced. The content of his third *annus mirabilis* paper, *On the Electrodynamics of Moving Bodies*, constitutes the miracle year's absolute highest point, and is, to me, the most emblematic of what made Einstein such a transcendent genius. His ability to see the universe with fresh eyes — unburdened by the assumptions built by previous generations — and generate a truly original framework will be shown in full force.

Special relativity challenges our most basic notions of space, time, and motion. We will not be able to fully develop every idea contained in Einstein's paper, and our approach will diverge somewhat from his to keep things simple. Nonetheless, you will see how fundamental its subject matter is to how we perceive the universe.

Galilean Relativity

The story of special relativity begins hundreds of years before Einstein with another truly great physicist: Galileo Galilei. Although he is best known for astronomy and heliocentrism, Galileo made significant contributions to the laws of mechanics. In particular, he formulated the so-called Galilean principle of relativity, which constitutes one of two fundamental postulates that Einstein used to derive his theory of special relativity [1]. However, to understand Galilean relativity, we must first take a detour to talk about reference frames.

You can think of a reference frame as the camera through which you are viewing the scene. Imagine someone named Alice is on a train moving at some speed v and passes another person named Bob, who is standing still by the side of the tracks. A camera centred on Bob would see him as stationary and Alice as moving through the shot at a speed v. Conversely, a camera tracking with Alice would see her as stationary and Bob as moving through the shot with a speed v in the other direction. Although we usually think of Bob's reference frame as being 'more correct,' this is only because we spend most of our time stationary with respect to the Earth's surface. Both perspectives are equally valid.

Suppose Bob is throwing and catching a ball for fitness and for fun. If he throws the ball directly upwards, it will rise and fall without deviating sideways and he will not have to move to catch it. Now imagine that Alice repeats this experiment on the train. She stands still within the carriage and throws the ball directly up. What happens? Does the ball, knowing that the ground is moving beneath Alice, start deviating towards the back of the carriage, forcing her to move to catch it? No. Rather, Alice observes exactly the same behaviour as Bob: the ball rises and falls in a direct line above her. None of the physics changes when you change reference frames. Importantly, that is only true because the train is not speeding up or slowing down as the ball is in the air. Any acceleration will change the result. For that reason, we specifically deal with *inertial* reference frames — ones which are not undergoing any acceleration. With that established, we can now state the Galilean principle of relativity [1]:

The laws of motion are the same in all inertial reference frames.

In other words, matter has no preferred reference frame; it is impossible to perform an experiment that will tell you which inertial frame of reference you are in. It is very fortunate that this is true, actually. The Earth is hurtling around the Sun at 107 000 kph, so the laws of motion would be very warped indeed in everyday life if it mattered that we were not at rest compared with the Sun (or the rest of the galaxy).

A Not-So-Light Matter

Our story now moves forward a couple of hundred years from Galileo to James Clerk Maxwell — another scientist who is very close to Einstein on the Good-At-Physics leaderboard. Maxwell's most noted contributions to physics are the so-called Maxwell's equations that describe the behaviour of the electric and magnetic fields. There is a great deal which can be said about Maxwell's equations, but for our purposes, only one fact matters: Maxwell used his equations to prove that light is a wave in the electromagnetic field that will travel in a vacuum at the speed c = 300 000 000 m/s [2]. This was a triumphant moment which finally answered one of the most significant problems in physics, namely the nature of light. However, physicists quickly noticed that a major issue arose when Maxwell's result was applied to the Galilean principle of relativity.

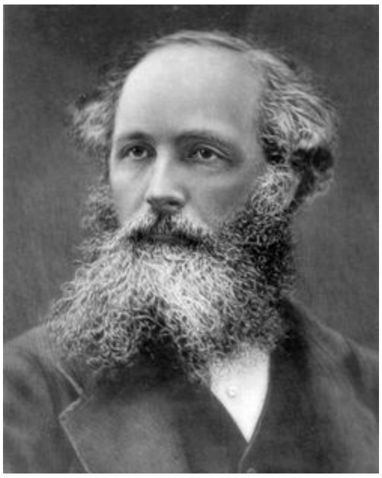


Figure 2: James Clerk Maxwell

Maxwell's equations are laws of physics, just like Newton's laws. We know from Galileo that Newton's laws of motion are the same in all inertial reference frames, so is the same thing true of Maxwell's equations? If so, that implies that the speed of light (in a vacuum) is c in all reference frames, since the speed of light is a direct prediction of Maxwell. However, this forces us to conclude a seemingly nonsensical result.

Let's return to Alice, Bob, and the train. If Alice, on the train, is moving at a speed v with respect to Bob, and Alice throws a ball forward at a speed u, then we would naturally expect that Bob sees the ball moving forward at a speed $v + u$. However, Galileo and Maxwell are now telling us something quite different about light. If Alice, instead of throwing a ball, shoots a beam of light at a speed c, we would expect Bob to see it moving at a speed $v + c$. However, what the Galilean principle of relativity would claim, if it applies to Maxwell's equations, is that Bob also sees the beam of light moving at a speed c. This seems like a contradiction. How can the apparent speed of light not change depending on your motion relative to it? Galilean relativity must not apply to Maxwell's equations. For light, there must be such a thing as a preferred reference frame, and it is possible to detect inertial motion relative to that frame.

Scientists moved quickly to justify why light would have a preferred reference frame. The foremost theory was that electromagnetic waves move through some medium (called the aether), and the speed of light is only c with respect to the reference frame in which the aether is stationary [3]. If so, then the Earth's motion with respect to the aether ought to be detectable if a sufficiently precise experiment could be devised.

A device known as a Michelson interferometer, named after its designer Albert Michelson, could detect the relative speed of two light waves that travelled in perpendicular directions [4]. If the Earth moves relative to the aether, then a beam of light travelling parallel to the 'aether wind' will move at a different speed to one travelling perpendicular to said wind. In 1887, Albert Michelson and Edward Morley built an interferometer that they believed would be precise enough to detect that difference. However, when the experiment was conducted, they detected no absolute aether wind [5]. The Michelson-Morley experiment became perhaps the most famous failed experiment in history.

One candidate explanation for this failure was that the Earth dragged the aether with it, perhaps by gravity. That, however, failed to explain other observations, like the aberration of light. Other explanations were proposed, but there was no satisfying physical interpretation of the experiment. The outcome of the Michelson-Morley experiment (and subsequent repetitions and improvements on it) posed major problems to the physics community. Some of you may be noticing a close correspondence between this story and that of the ultraviolet catastrophe which led Einstein to quantum mechanics in his first *annus mirabilis* paper: an unexpected experimental result and no satisfactory explanation to be found. All of the best scientific work happens in that space of uncertainty. All of the hardest scientific work, too, but that's what miracle years are for.

The Two Postulates

While other scientists tried continuously to rework the aether theory to account for the Michelson-Morley null result, Einstein did what he did best: thinking so far inside the box that it sounds like he's thinking outside the box. Einstein decided to move away from the aether and instead returned to Galileo. He asked himself what would happen if we took Galilean relativity really seriously. What would that imply? He began from just two postulates [6]:

1) The laws of motion are the same in all inertial frames
[Galilean relativity]

2) The speed of light in a vacuum is c in all inertial reference frames
[Maxwell's equations are subject to Galilean relativity]

Thus, special relativity was born. As we shall see, the consequences of these two postulates are patently absurd. But the theory that was born from them has become one of the most precisely verified and universally accepted theories in the history of science.

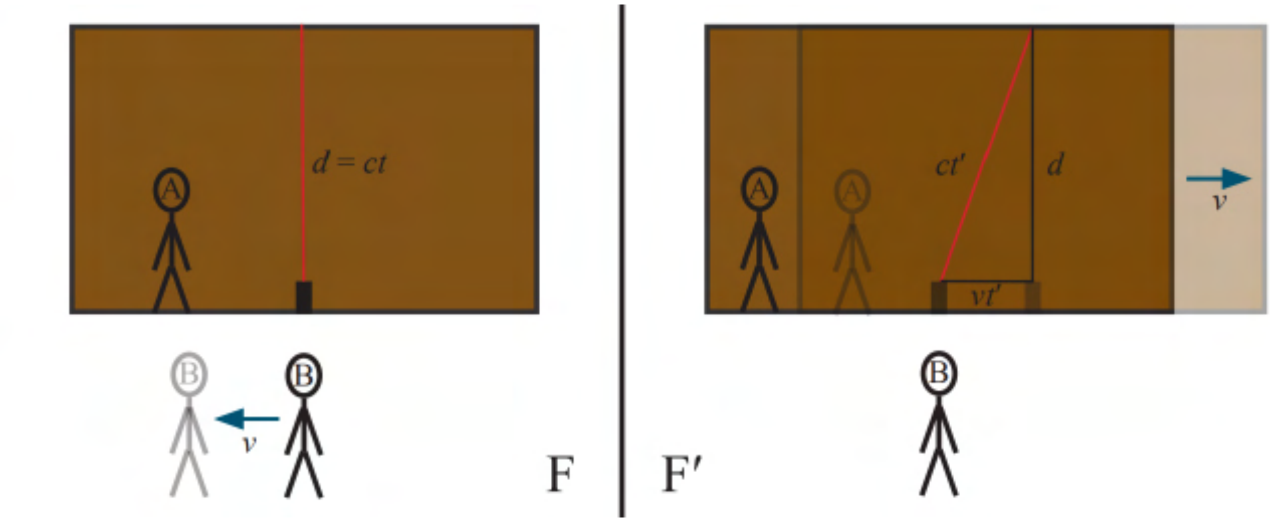


Figure 3: A laser beam moving from the floor to the roof of a moving train from two different perspectives. Alice sees the light move directly upwards, whereas Bob sees it angled to match the changing horizontal position of the train.

Time Dilation

Let's return to Alice and Bob. Alice, on the train, has a laser which will send a beam of light from the floor to the roof — a distance of length *d*. Both Alice and Bob watch this happen and measure how much time the light beam seems to take to travel that distance. In the reference frame co-moving with Alice, which we will call F, the light travels at a speed *c*, and therefore takes a time $t = d/c$ to travel from the floor to the roof. In Bob's reference frame, F', however, the light does not travel directly vertically, but has some horizontal motion as well. If F' is travelling at a speed *v* with respect to F, then from Fig. 4 (and using Pythagoras' theorem) it is clear that Bob sees the light travel a longer distance. We have:

$$d = ct$$

for Alice, but

$$\sqrt{d^2 + v^2 t'^2} = ct'$$

for Bob.

Substituting Alice's expression into Bob's and rearranging gives the absurd relation:

$$t' = \frac{1}{\sqrt{1 - v^2/c^2}} t$$

Alice and Bob measure completely different time intervals between the light leaving the floor and hitting the roof. Time is moving more slowly for Alice!

This phenomenon is known as time dilation. The time measured between two events depends on the reference frame you are in. Let us define the factor γ by

$$\gamma = \frac{1}{\sqrt{1 - v^2/c^2}}$$

As *v* increases from 0 to *c*, γ increases from 1 to infinity. This means the shortest possible time (known as the 'proper time') is measured in the reference frame in which the two events are stationary (where $v = 0$) — Alice's frame, in our example. Any other reference frame will measure a longer time interval (since $v \neq 0$ implies $\gamma > 1$), and the greater the relative velocity between reference frames, the longer the time interval will be.

Time dilation is a shocking reality to confront. If you had a twin who became an astronaut and travelled to Alpha Centauri at a speed close to the speed of light, the journey would seem to take around four years to you, but they may have only experienced a few weeks. You would still be twins, but no longer the same age.

Interestingly, time dilation is a phenomenon that may allow us to feasibly colonise incredibly distant planets. If we find a planet on which humans could live but which is thousands of lightyears away, it would seem impossible for us to reach it before the colonists on the spaceship died. However, due to time dilation, a thousand-year journey could constitute just a few hours of a colonist's life if the ship were fast enough. Unfortunately, those on Earth would not live long enough to find out if the ship arrived at its destination, unless our lifespans increased by a couple of thousand years.

Length Contraction

The bending of reality does not end with time dilation, though. Now let's imagine that Alice and Bob both try to measure the length of the train. To do that, they both measure the time taken for the entire train to pass Bob. Alice gets:

$$L = vt$$

and Bob gets:

$$L' = vt'$$

But remember that t and t' are not the same. This time, our two events are the front and back ends of the train passing Bob. These two events happen at the same place in Bob's frame, so he measures the proper time. Alice, therefore, measures a time lengthened by a factor of

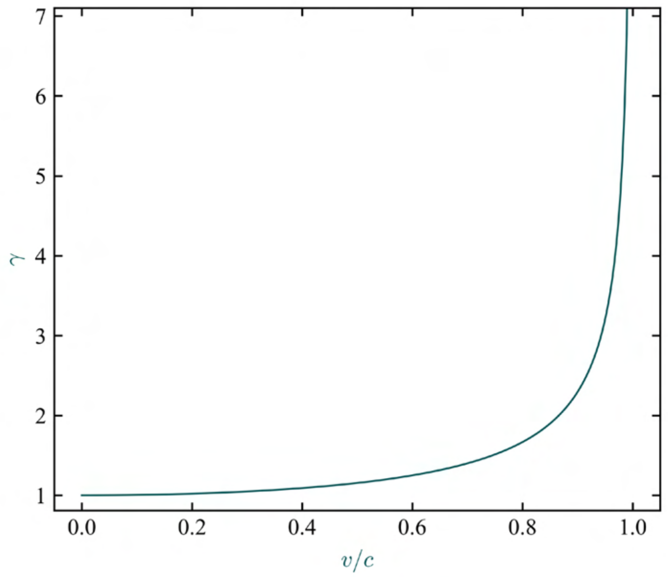


Figure 4: A plot of γ (known as the Lorentz factor) against reference frame speed as a fraction of the speed of light. The larger γ becomes, the more distorted space and time are when compared across reference frames.

gamma. Substituting that relationship into these two length equations yields:

$$L' = L/\gamma$$

So the size of an object — the distance between two points — depends on the reference frame as well. The longest possible length (known as the proper length) is measured in the reference frame in which the object is stationary — Alice's frame, where the train is motionless. The object's length in any other reference frame is shortened by larger and larger proportions as the relative speed between reference frames increases. This is length contraction.

Velocity Transformations

As we have seen, both time and space are distorted when comparing inertial reference frames. We must expect, then, that the velocity of an object (how quickly its position changes as time increases) will also defy our intuition. If Alice throws a ball forward on the train at a speed u, at what speed u' will Bob measure it to be travelling? Pre-Einstein, the answer would be $u + v$. Post-Einstein, however, the answer becomes something more bizarre:

$$u' = \frac{u + v}{1 + uv/c^2}$$

This equation has an important consequence. If Alice throws the ball at the speed of light, i.e., if $u = c$, then the speed Bob measures is:

$$u' = \frac{c + v}{1 + cv/c^2} = \frac{c(1 + v/c)}{1 + v/c} = c$$

In other words, something travelling at the speed of light in one reference frame is travelling at the speed of light in any reference frame. This was one of our postulates, so we are seeing that the theory of special relativity is self-consistent. Furthermore, any speed u in *any* reference frame v will always be measured as less than the speed of light. There is a universal speed limit: c. Nothing can travel faster than the speed of light.

Simultaneity and Causality

With time and space now fully bent — and our brains bent with it — let us now turn to a thought experiment that brings to light an apparent contradiction in special relativity. Alice's train hurtles towards a tunnel that is half the length of the train. At each end of the tunnel are enormous guillotines that Bob can control and which would destroy the train if it were in the wrong place at the wrong time. When Bob sees that the train is exactly in the middle of the tunnel, he drops both guillotines simultaneously, but finds that nothing at all happens to the train. How can that be the case? Well, fortunately for Alice the train was travelling at 90% the speed of light, so length contraction meant the train was less than half its proper length (and therefore able to fit entirely within the tunnel) in Bob's frame of reference.

That sounds all fine and dandy, given what we know about special relativity. The contradiction, however, comes when we try to view the same situation in Alice's frame instead of Bob's. In her frame, the train is stationary, and therefore its length is *not* contracted. Furthermore, the tunnel is moving towards her at 90% the speed of light, and therefore it is contracted to less than half its proper length (i.e., less than 1/4 the length of the train). There is no way for the train to fit entirely inside the tunnel, and therefore it is impossible for it to survive when the guillotines drop simultaneously. It would seem, then, that Alice sees her train being cut into pieces. How can the train be destroyed according to one observer, but remain unscathed according to another? Though different observers will perceive space and time differently, they must surely agree on what actually happens to the train, right?

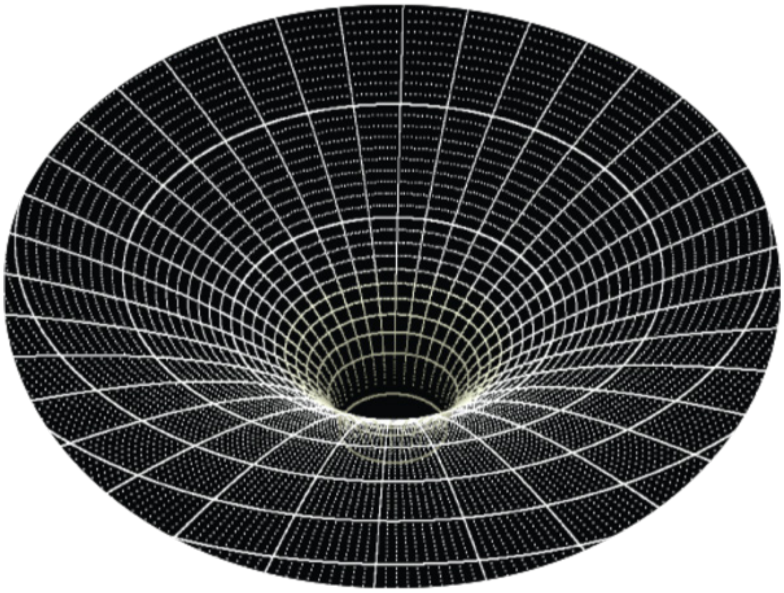


Figure 5: Ten years after inventing special relativity, Einstein would take the idea of spacetime even further. His general theory of relativity describes gravity as curvature in spacetime, leading to diagrams such as this (acquired from pngwing.com).

The resolution of this paradox comes by challenging something I implicitly assumed in my description of what Alice sees. Just because the two guillotines drop simultaneously in Bob's reference frame does *not* mean they drop simultaneously in Alice's reference frame. Alice survives in her own reference frame because she sees the far guillotine drop first (before she reaches it), then a pause before the rear guillotine drops after she has passed it by. The order of events can depend on the reference frame through which they are viewed! The concept of time in special relativity is entirely different to what we normally experience. There is no absolute 'present' across all reference frames, and different observers can disagree on the order in which events occur. This is the relativity of simulteneity.

The final complication to this rearrangement of events is causality. If one event causes another, their order cannot be switched. Fortunately this is accounted for in special relativity via the universal speed limit *c*. It is only possible for one event to cause another if a signal travelling at the speed of light (or slower) can leave the first event and reach the second one on time. If they are too far apart, no information about the first event can influence the second. The maths of special relativity says that the order of two events can only be switched if a beam of light could not travel between them, so causality is preserved.

Spacetime

Throughout this article, I have been referring to space and time separately, but almost always in conjunction. Pre-Einstein, space and time were viewed as entirely disjoint entities. However, the more you learn about special relativity, the more linked these two aspects of reality become. Indeed, Einstein's third *annus mirabilis* paper unified them through the concept of a spacetime interval.

Before special relativity, we believed that distances were the same no matter what reference frame you were in. If two objects are separated by distances x, y, and z in the three spatial dimensions we experience, then the value $r^2 = x^2 + y^2 + z^2$ was invariant across frames of reference. However, we now know that length contraction exists and therefore the Euclidean distance r is not preserved. As length is contracted, though, time is dilated. So, Einstein was able to discover a new value called the spacetime interval between two events, $s^2 = t^2 - x^2 + y^2 + z^2$, that was the same in any reference frame. The spacetime interval replaces the notion of distance in special relativity. Space and time were no longer separate entities, but rather two parts of a larger fabric of spacetime. This is why we now say that we live in a four dimensional universe, as opposed to three.

Spacetime addresses the interesting oddity in special relativity that is the universal speed limit. It seems strange that any speed is possible less than *c*, but nothing can move faster. It's almost asymmetrical in that way. When space and time are unified, though, a rather pleasing resolution to that awkwardness manifests itself. We know that the faster a reference frame is moving, the more slowly time is passing in that reference frame. In other words, the faster something moves through space, the slower it moves through time. So, it is not really the case that any speed is possible; instead, *there is only one speed*. Some objects are stationary and are moving forward through time at a 'speed' *c*, while others are using some of their speed to move through space instead, and hence move more slowly through time. Everyone and everything is travelling at the speed of light, just in different directions.

Not the End

This article is overly long already, yet I haven't even covered half of what Einstein spoke about in his paper, nor was this the last paper he wrote on the subject. Furthermore, you may have been wondering why we call special relativity "special" relativity, not just relativity. The answer is that special relativity is merely a special case — a subset — of the more general theory of general relativity, which also incorporates non-inertial frames of reference. *General* relativity was unleashed on the world by Einstein in 1915 and has become, along with quantum field theory, one of the two pillars of modern physics. Without special relativity, though, general relativity would not have been possible.

Special relativity is an extraordinary topic that forces you to really think like a scientist — casting off your assumptions. We are now three papers into Einstein's 'miracle year', and it is becoming increasingly clear why 1905 is now known by that name. The fourth and final *annus mirabilis* paper will be an elaboration on some aspects of special relativity which we have not mentioned, notably giving rise to the most famous equation in history: $E = mc^2$. That will be the topic of my next article here in *UoA Scientific*.

Caleb Todd - BSc (Hons), Physics

Caleb is a Research and Teaching Assistant in the Department of Physics at UoA newly finished with his BSc(Hons) degree. His research is in nonlinear optics and laser physics; in particular, the dynamics and control of ultrashort pulses of light.

Mysterious *Wolbachia* Bacterium Helps Fight the Dengue Virus

Sarah Moir

Figure 1: Mosquito image by Yogesh Pedamkar from Unsplash.

If you're traveling to the Caribbean, Indonesia, Australia, or any tropical climate really (where else would you holiday), falling ill to the dengue virus may be in the back of your mind. And you would be smart to pack the mosquito repellant; dengue fever is a serious and potentially fatal disease without any specific treatment nor preventative medicine. More significantly, dengue burdens millions of people that inhabit the endemic habitat of *Aedes aegypti*, the carrier mosquito; endemicity that is rapidly spreading towards European and North American populations thanks to climate change. Over the past decade, reported dengue virus (DENV) cases to WHO has increased eight-fold to 5.2 million in 2019 [4]. Asia disproportionately represents 70% of the dengue burden, thought to be an effect of rapid urbanisation and global warming [1]. Thus, social and environmental issues should be taken into consideration when responding to the dengue outbreak. The lack of viable vaccines and specific treatment spotlights *Wolbachia* bacterium as a cheap and effective solution through a somewhat known, yet mysterious, symbiosis.

Dengue is a positive-strand RNA arboviral disease of the four serotypes DENV 1-4, belonging to the Flavivirus family [2]. *Aedes aegypti* mosquitoes are its primary vector, facilitating the carrying and spread of DENV amongst populations [3]. Humans also reservoir DENV, infecting mosquitoes who feed on them [4]. The route down DENV infection involves E proteins embedded within the viral lipid membrane, of which bind to cellular receptors to initiate endocytosis (entry into the cell for amplification and replication) [2]. Another pathway, the Antibody-Dependent Enhancement (ADE) pathway, is associated with greater disease severity or potentially fatal dengue shock syndrome. The ADE pathway exploits processes of the immune system. Fc immune cell receptors bind antibodies (bound to pathogen DENV) for endocytosis but also act to block key antiviral molecules such as cytokines, which are regulators of the immune response [5]. DENV acts to decrease transcription and translation of pro-inflammatory cytokines and increase transcription and translation of anti-inflammatory cytokines. Such imbalanced inflammatory responses cause inner blood vessel lining pathology and vascular leakage, leading to hypovolemic shock [2]. Dengue prevalence is attributed to *Aedes aegypti*'s life-long infectiousness and high transmission, but the spread of Dengue is compounded by social and environmental contributors discussed in coming chapters [2].

Wolbachia

To control the dengue burden, research in vaccines, antivirals, and vector-control has been discernible over the past decade [3]. However, lack of effective vaccines has left vector control the pertinent method for reducing viral spread [6]. Endosymbiont *Wolbachia*'s protection against significant infection of RNA viruses, and thus reduction of dengue infectivity in *Aedes aegypti*, has been known for years despite the lack of consensus on the underlying mechanisms. *Wolbachia* are maternally inherited bacteria known to infect >65% of insect species, yet do not naturally infect *Aedes aegypti* [7]. Fortunately artificial infection is feasible, thus, opening the door to potentially effective and naturally dispersive vector control.

Pan et al. [7] proposed the establishment of symbiosis between *Wolbachia* and its host to increase pathogen resistance. *Wolbachia* exploits host innate immunity by activating toll and immune deficiency (IMD) biochemical pathways. This is via activating pattern recognition receptors (proteins capable of recognising pathogenic molecules); both of which induce the expression of antimicrobial peptides, which in turn induce overexpression of antioxidants. Pan et al. acknowledge that it is unknown how these pathways reduce DENV infection and facilitate symbiosis, although it is clear upregulation of such pathways increases *Wolbachia* presence. For example, antioxidant enzymes induced by Toll pathways are suspected to enhance *Wolbachia* fitness [7]. This is supported in another study, where increasing fly survivability in hyperoxic conditions was shown to have high antimicrobial peptide and antioxidant presence [8]. Antimicrobial peptides potentially maintain the *Wolbachia* niche in preventing the growth of microbial flora within mosquitos [7]. As described above, *Wolbachia*'s exploitation of a host's immune response allows it to beat its microbial competitors. Evidently, boosting mosquito immunity with *Wolbachia* could both amplify *Wolbachia* titer (populations) and resistance to DENV.

Figure 2: Poor infrastructure, drainage and sanitation are depicted as a consequence of rapid urbanisation in Vietnam. Vietnam, like Bangladesh, manages the dengue burden seasonally and with increasing severity. Image by Tony Lam Hoang from Unsplash.

A secondary speculated mechanism suggests *Wolbachia* may out-compete DENV for important host cell components including cholesterol, by which *Wolbachia* nor Flavivirus' have the biosynthetic capability to synthesise autonomously. Interestingly, DENV requires cholesterol in order to replicate and cause pathogenesis [6]. The significance of competition between *Wolbachia* and DENV is yet to be determined, however, it sounds like it could be a key area of focus in future studies.

Thinking beyond *Wolbachia*

The importance of DENV control is reinforced when considering the implications of both urbanisation and global warming on the dengue burden. *Aedes aegypti* survival, reproduction and transmission are promoted by increase in temperature, annual precipitation and humidity [10]. Bangladesh exemplifies how *Aedes aegypti* exploit such climatic shifts where the 2015-2017 pre-monsoon season saw seven times more dengue cases than the 2000-2017 season [11]. Rapid urbanisation was also linked to increasing dengue cases in Bangladesh. Poor health care, infrastructure, sanitation, waste disposal, and drainage facilitates increased transmission and mortality in such metropolitan agglomerates [12]. Both global warming and urbanisation extend *Aedes aegypti* habitat beyond endemicity where human interaction with zoonotic (animal-borne) disease increases with deforestation and extension into wild habitat whilst tropical boundaries continually stretch toward the poles [13]. In 2015, approximately 53% of the global population was modeled to inhabit dengue risk areas, and was projected to increase to 60% in 2080 [10].

If you haven't thought about COVID-19 enough, the latest pandemic exemplifies the ways in which increasing viral transmission in a warmed and urban climate may indirectly impact the dengue burden. Co-infections, lack of discrimination between COVID-19 and DENV in both clinical presentations and diagnostic methods, as well as access to healthcare may overrun such systems and put patients at further risk [14]. Communities vulnerable to such consequences of global warming and rapid urbanisation reinforces the need to explore beyond purely biological solutions.

Dengue is considered as one of the fastest growing viral diseases today, now extending beyond endemic boundaries consequential to urbanisation and global warming [4]. Vector control methods using *Wolbachia* bacteria is a promising area of research. However, unresolved consensus on the mechanisms of DENV control leaves more research to be done. Not only is *Wolbachia* potentially protective against dengue, but also for other diseases including malaria, yellow fever, and zika. *Wolbachia* is thus a significant bacterium that may potentially lead the fight against mosquito-borne disease for the protection of human health over the coming years.

Sarah Moir - BSc, Biological Sciences

Sarah is in her third year of study at UoA as a Biology major. Interested in disease, immunology, and development, she is excited to dive into postgraduate study over the following years.

Going Incognito: The Invisible Universe of the Nanoplastic Pandemic

Eugene In & Nargiss Taleb

The Plastic Pandemic

With the mass production of plastic in the 1940's, humans have come to live lives of convenience and ease. What manufacturers didn't anticipate was the vast distances across which these plastics would eventually travel — remote places such as the Balcony of Mt. Everest [1] and Antarctic ice cores [2], the digestive tracts of marine organisms [3], even in our own blood [4]. It's everywhere. Although the idea of plastic pollution has been around since the 1970's [5], it hasn't been until this year that the extensive impacts of this have been acknowledged. The beginning of March marked a historic event in which the United Nations declared by 2024 to have created an international treaty addressing the plastic problem at each stage of its lifecycle. From looking at more environmentally friendly alternatives to the management of its waste, the treaty is an awesome step in the right direction.

However, many of the mitigation steps still require us to know exactly where our plastic is in order to help regulatory communities assess their risk. Plastic in the environment is fragmented and degraded into smaller particles via various natural processes; UV-induced, thermal, and microbial processes to name a few [6]. The plastic lifecycle is long. Large (bulk) plastics degrade slowly into the well-known microplastics (akin to those of exfoliant beads in face scrubs), and eventually weathering, fragmenting over time (in various environments) into smaller nanoplastics. Plastic degradation is infinite, and has given rise to the scientific quest of detecting these seemingly 'invisible' plastics. Microplastics and larger fragments already have methods of detection and isolation that are long established; however, their even smaller counterparts, nanoplastics, have slipped under the radar, incognito if you will.

Only emerging in scientific literature in the last seven years, the implications of nanoplastics for human health and the environment are still riddled with uncertainties. Nanoplastics themselves are yet to have a standardised definition of their size. The issue stems from the vastly different physical and chemical properties these nano-sized materials exhibit, and by their behavior, while interacting in our macroscopic world. Understanding these materials seems unattainable (for now). While we combat the nanoplastic threat socially, the first line of active defense comes with detection. With our research, we reached our small victory in just that. Nanoplastics are invisible no more.

Before things get underway, let us introduce to you our weapon of choice, Raman Spectroscopy — the detection method that gives the possibility of pinning nanoparticle contaminants on our pollution radar.

Raman Spectroscopy

By shining a red light onto a material, you would expect the exact same colour to be reflected back. A Raman spectrometer, however, can measure that a small fraction of this reflected light is a different colour. This is a result of molecular vibrations causing a change in the energy, and therefore, the frequency of the light being scattered. As each chemical bond has its own associated energies, individual bonds (eg. C-O, C-H) and groups of bonds (e.g. benzene rings) exhibit different energy shifts and therefore, can be identified by their peak position in the Raman spectra. The benefits of Raman are the incredibly simple sample preparation and non-destructive nature of characterisation [7]. It is typically an effective technique for polymer identification — however, nanoplastics are unable to generate signals strong enough to give rise to spectral peaks. So, how can we use this vibrational technique to detect nanoplastics?

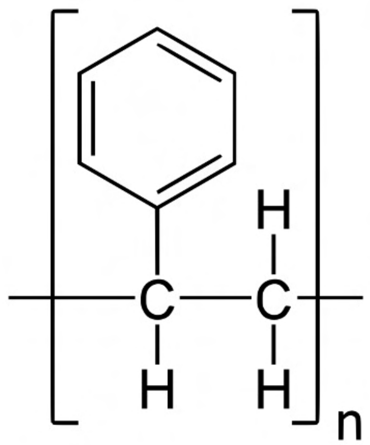


Figure 1. Polystyrene molecule.

Surface-enhanced Raman spectroscopy (SERS) is a technique introduced to overcome some of the limitations of traditional Raman spectroscopy. By using metallic nanoparticles, the electric field surrounding the metal surface is enhanced, allowing the amplification of scattering signals when interacting with the analyte.

Our Approach

As summer interns part of Professor Duncan McGillivray's Soft Matter group, we leaped into this exciting project, developing methodology for the detection of polystyrene nanoparticles. The studies involved the synthesis of spherical gold nanoparticles (AuNP) acting as our electric field enhancing material, this being used to detect polystyrene nanoplastics as our analyte of interest (Fig. 1).

To lay the foundations, a batch of ca. 20 nm AuNP's were synthesised via an experimentally-optimised Reverse Turkevich method [8], which involves a particular ordered addition of key reagents. This method was named after the original publication by Turkevich et al. in 1951, for the synthesis of nano-sized spherical particles between the size range of 10 to 30 nm [9]. Frens in 1973 revised this method for ensuring monodispersity (uniform particle sizes) of colloidal gold nanoparticles [10]. The original Turkevich method requires a certain order of reagent addition (chloroauric acid ($HAuCl_4$) to trisodium citrate ($Na_3C_6H_5O_7$)), with the reversed method requiring the inverse starting material addition — trisodium citrate added to the boiling gold solution. The monodispersed AuNP suspension was synthesied via reflux, giving it an overall characteristic ruby red colour (think cranberry juice).

Using this suspension, we created a system analogous to an open sandwich. The first layer or the 'bread' is a cellulose filter paper. The AuNP suspension once diluted was mixed together with a 1 mg mL^{-1} positively charged polystyrene suspension (Fig. 2), and was deposited (drop-casted) like a 'spread' onto the filter paper. Once dried, the monochromatic red laser (785 nm) of the Raman Spectrometer is shone

Figure 2. The system of AuNPs (-) and polystyrene (+) aggregates in a 1:1 mixture due to having opposite charges.

through a X50 microscope lens at 50 mW power. Our vibrational spectral data was collected from a wavenumber range of 200-1800 cm^{-1}, with a 20 s scan acquisition time. An example of the experimental set up is seen in Fig. 3, Fig. 4.

Finding Nanoplastics — Unveiling the 'Invisible' Nano-world

Our results were astounding, with consistent enhancement of characteristic styrene peaks from our analyte of interest, which was positively charged 20 nm polystyrene (a common plastic). Selective polystyrene peak enhancement signals

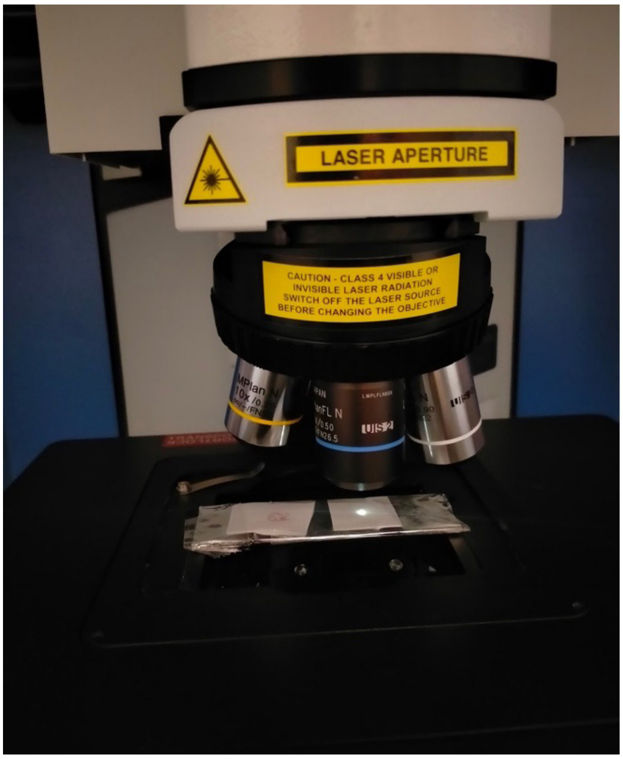


Figure 3. Inside a Raman Spectrometer lies a sample of a AuNP/ polystyrene system drop-casted onto cellulose filter paper.

over the filter paper matrix with an AuNP capped surface was key to recording successful SERS signals.

With SERS effects, we can quantify the increase in signal strength via calculation of the enhancement factor (we will spare you from the math). Selective styrene peak enhancements presented enhancement factors of 110-1750, and in some cases, 3050 times the original signal strength were identified (Fig. 5). Excluding the 20 nm AuNP plasmon band at 518 nm, styrene related Raman signals include the aromatic C=C ring deformation (620 cm^{-1}), C-C ring stretch (1004 cm^{-1}), and C-H in-plane deformation (1030 cm^{-1}). With this knowledge, we further explored the limit of detection of the filter paper SERS substrate with Raman measurements of samples with lower concentrations of polystyrene (500, 100, 50, 10, 5 and 1µg mL^{-1}). From this we found consistent nanoplastic detection of polystyrene at concentrations of 10 µg mL^{-1}, with instances of an all-time lowest detection limit of 5 µg mL^{-1} when compared to recent literature outputs.

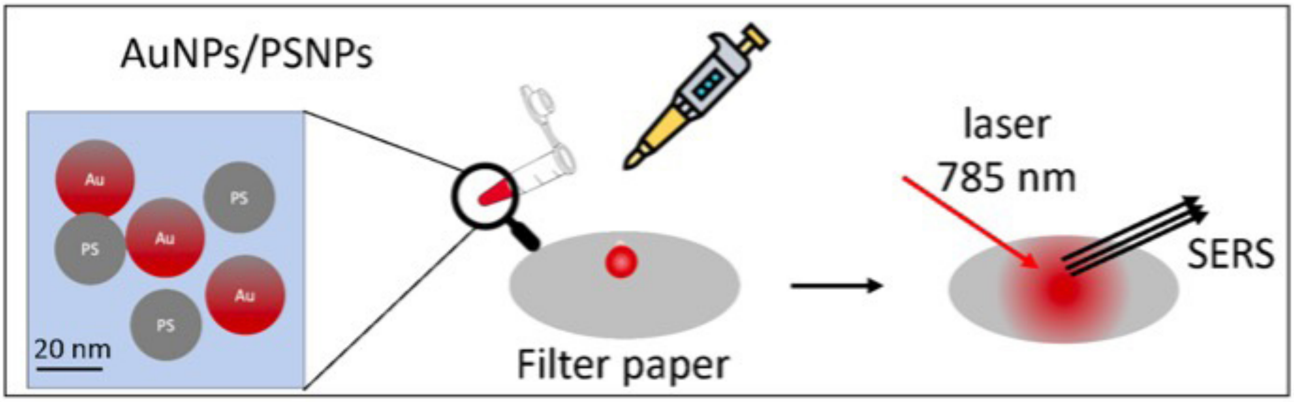


Figure 4. A schematic illustration for the filter paper system developed in this work.

Although we had successful results in a laboratory setting, these are not necessarily representative of its native state in the environment. The effect of salt (NaCl) was tested using 150 and 600 mM concentrations, this being physiologically and seawater relevant, respectively. It was found that our ability to detect nanoplastics had reduced by a factor of 10, and our system's limit of detection was reduced to 100 µg mL^{-1}.

Conclusion and Future Work

Based on our filter paper-based investigation to uncover the seemingly 'invisible' polystyrene peaks, the developed SERS system presented a robust and efficient detection method for dilute nanoplastics in a selective manner. Consistent and reproducible styrene peak enhancements at characteristic vibrational spectroscopic stretching modes were isolated — with ability to enhance dilute concentrations of nanoplastics. Strong enhancements of positively charged polystyrene were identified, with a reliable limit of detection of 10 µg mL^{-1}, and even as low as 5 µg mL^{-1}. Notably, the average enhancement factor of polystyrene Raman peaks ranged from ca. 1100-1750, with an instance of enhancement performance of ca. 3050 across various AuNP batches. Our findings put to question how the interparticle distancing between the AuNP and PS spheres (mechanism) effect the enhancement factors, which can be explored using more complex methods such as small angle neutron-scattering (SANS), and small angle x-ray scattering (SAXS). To do this, a trip across the ditch to our Australian friends would be required.

Whilst we are far from reaching complex detection of nanoplastics from an environmental system with various competing matrices, our research questions the realm of nanomaterial toxicity in and around our complex, macroscopic world. Such research into the complex nanoplastic interactions are still to be pioneered. Nevertheless, a positive step forward in combatting and unveiling the 'invisible' plastics in simple systems offer a great potential for building on a foundation of nanoplastic detection methods, and is a small contribution (but perhaps the ultimate key) in nanotoxicology research.

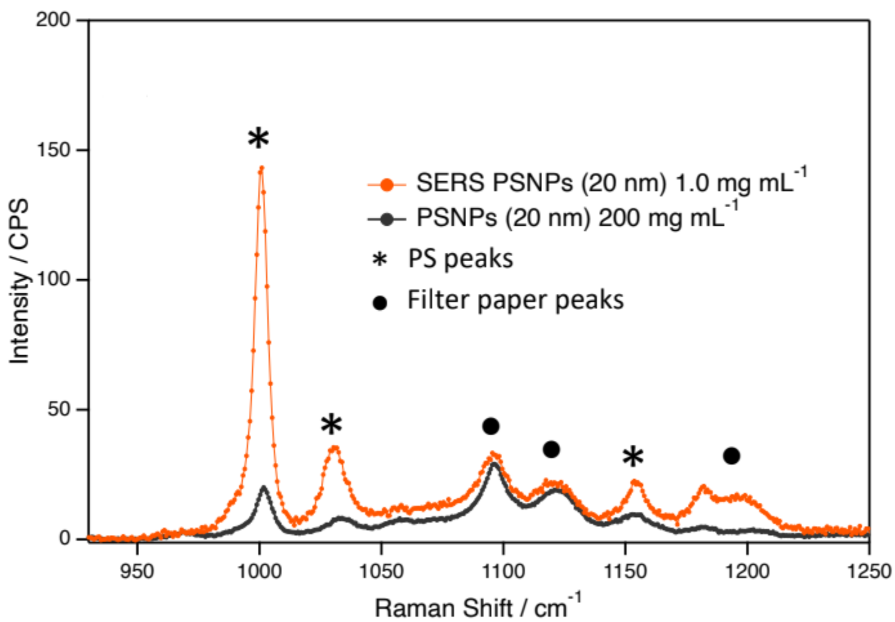


Figure 5. A representative surface-enhanced Raman spectra for PS(+)20 (1.0 mg mL^{-1}) with AuNP (orange) and non-enhanced PS(+)20 (200 mg mL^{-1}) (black).

Acknowledgements

We were lucky enough to have jumped into this project as research interns and assistants with some amazing mentors, who we cannot thank enough for the depth of knowledge and skill development they have provided us. Thank you for teaching us to be critical and see the true art of science, and inspiring us to be better scientists and people. Thank you for the endless support and laughter, and all the banter over our many burger trips. Thank you Andrew Chan and Shinji Kihara! Absolute legends.

Eugene In - BSc, Chemistry & Psychology

Eugene is in her final year of BSc, with interests in synthetic chemistry and neuroscience. Her interest in research are in bio-inorganic chemistry, quantum neural networks and synaesthesia. A musician, and ex-competitive swimmer - she is passionate about learning, fitness and classical music, as well as breaking systematic inequities as a woman in STEM.

Nargiss Taleb - BSc (Hons), Green Chemical Science

Nargiss has undertaken a BSc Honours with the motivation to inspire sustainable change in the environment using chemistry. With a passion for the environment comes an interest in anthropogenic contaminants, including nanoplastics. Her research involves understanding how nanometal shape and its spatial interactions allow for nanoplastic detection using Raman spectroscopy.

An adapted interview with Dr Rosie Bosworth from 95bFM's 'Tomorrow's World' about what the future holds for the mass production of meat.

THE FUTURE OF FOOD

Our eating habits reflect our biological needs, cultural practices, and accessibility to resources. Aotearoa is facing mounting sustainability issues and Fonterra has recently been named the highest carbon emitter in the country, after reporting over 13 million tonnes of greenhouse gas emissions to the Environmental Protection Authority. Dr Rosie Bosworth is a specialist in the future of food, with a PhD in environmental innovation and sustainable technology development. We interviewed her in 2021 on our radio segment, titled Tomorrow's World, which airs on 95bFM. We decided to revive this interview in light of growing food sustainability concerns for Aotearoa, and adapt it into a print article exploring the future of food. While it is well known that changing to a plant-based diet mitigates the effects of climate change in a myriad of ways, for some, a stark shift to entirely plant-based just isn't feasible. So, what could diets look like in the future if the entire planet can't go strictly vegan?

Is a vegan diet more sustainable?

Historically humans have consumed meat to satisfy nutritional needs. With hunting related to high danger risks and energy demand, a shift to intensified agricultural practices has increased with patterns of urbanisation [1]. However as wealth and resource extraction has concentrated into some regions, and populations have increased globally, the type and quantity of food produced has changed dramatically. In the last four decades global meat production through agriculture has increased by 20%, with 30% of the global land surface area used for animal production [2].

The normative practices of consuming meat within a daily diet has contributed to biodiversity loss and increased greenhouse gas emissions. However it is important to consider that the consumption of any resource comes at an expense. We asked Dr Bosworth how sustainable a vegan diet is:

"It is complicated, vegan food has so many types of 'plant based' options – some of which are being criticised for having a large footprint themselves – like almond milk. But there are now also more and more advancements in science and biotech which mean we can even produce the same proteins as those found in animals or dairy proteins themselves, without the animals, that don't require the use of plants as substitutes . When you're looking at plant based milks, almond milk gets a worse reputation than other plant based milks like oat or coconut, but even when you compare almond to dairy it is markedly more environmentally friendly, especially in terms of water use."

The idea of lab grown food, which Dr Bosworth refers to as 'biotech', has been rising in popularity. Even large fast food chains such as Burger King have released Beyond Meat® and Impossible™ Foods burgers.

So how do these cell based meat processes stack up sustainably? A life cycle assessment (LCA) considering the eutrophication, potential land use requirements, and greenhouse gas emissions of these alternative proteins compared to chicken, lamb, and beef (Fig 1) show a better performance for cell-based meats [3]. However, currently the energy consumption used by cell-based meat production exceeds all alternatives.

Cellular agriculture

[cellular agriculture is] "Taking cells from animals and growing these actual cells outside the animal. By feeding them a carbohydrate feed stock, we don't need all the energy source to produce that we do to grow animals over time to slaughter or raise as dairy cows. Another really cool process that's being advanced right now to produce dairy proteins and other molecules is precision fermentation. Precision fermentation involves programming yeast or fungi to produce the very same proteins and molecules like milk or cheese, without the animal, in large vats. Essentially, the cow is becoming an old piece of tech."

As a response to the long-term environmental degradation that traditional livestock agriculture creates, biotechnologists have conceived a new route of catering to the 21st century human's desire for meat: cellular agriculture. As Dr Bosworth mentions, the process is essentially taking a piece of animal tissue, relevant to the section of the animal we want to consume. Then, these cells are cultured, and given all of the nutrients in vitro that they would receive in vivo. They grow to maturity in a bioreactor (which is simply any man-made vessel that carries out biological processes) in the same manner an entire organism would grow in a field, and reach the same fate that such an organism would: they're harvested, and processed appropriately.

There are two distinct processes included in cellular agriculture, and they're not limited to producing 'meat'. Acellular products can create things like milk, for example, using a starter culture, inserting the gene that produces milk, an animal protein, into a microorganism. This means the process of milk production then occurs in a lab, outside of an animal, so we skip all of the excess maintenance of the animal that would occur, and jump right to the end result; the animal protein we desire. This is the process by which most medical insulin is made, and the host microorganism in that case is generally *E. coli*. These engineered microorganisms do all the work for us, and are markedly lower maintenance than farming an entire cow.

Cellular agriculture, alternatively, takes specific tissue from a biopsy, and is grown similarly to acellular products, with a scaffold and nutrients. Its differentiation is the fact that living cells are being cultured, rather than proteins. The main part of the meat we eat is muscle tissue, so this is where the biopsy is taken from.

Ethics

The ethics of cellular agriculture [4] could fill two entire volumes of this publication alone, so we'll simply outline them. There's a pro-stance, which argues that since we're avoiding the raising of livestock purely for the use of their resources and inevitable slaughter, the process aids animal welfare. And it's easy to see the arguments for this; we do indeed clearly bypass the possibilities of inhumane treatment, because we don't have a whole organism (in the traditional sense) to deal with. It also ties in neatly with the argument of sustainability; by avoiding the raising of a whole cow, we avoid the emissions that said cow creates, simply by its existence. That's avoiding a lot of emissions even before we get to the supply chain points of maintenance, space, land use, water consumption, then the myriad of processing that needs to happen after the animal's demise.

The inverse of these arguments is a tricky conversation: Gene-editing may be perceived as tied up with the ethics of 'playing God', and the implicit debate within these questions as to what the definition of 'life' is. Of course, these cells are 'living', but are they sentient? And how does that make a difference to how they should be treated? Answers to these questions are value-laden and boil down to a pretty detrimental issue for the process if left unresolved. If people are unsure about how they feel about this new technology, they A) won't participate or B) will actively rally against the concept. There's little point in developing technologies such as this, if they won't be accepted and adopted by the populus. Science often operates as a knowledge seeking exercise, and as catering to the needs and desires of the population; if no one's using it, it's a dead end.

Manipulating soy to mimic meat textures and tastes

"Heme (or leghaemoglobin) is a molecule found in cows but can also be bio-fermented and harvested using the same DNA found in soy root nodules. It's what gives meat that umami aroma and meaty rich smell and taste. [This is important because the] average consumer wants a similar experience with meat burgers – not a rubbery or bland soy product. There's a sensory experience that tofu may not give, and we need to offer the same sensory experience to get mainstream audiences to switch over."

As an alternative to cellular agriculture, the biofermentation

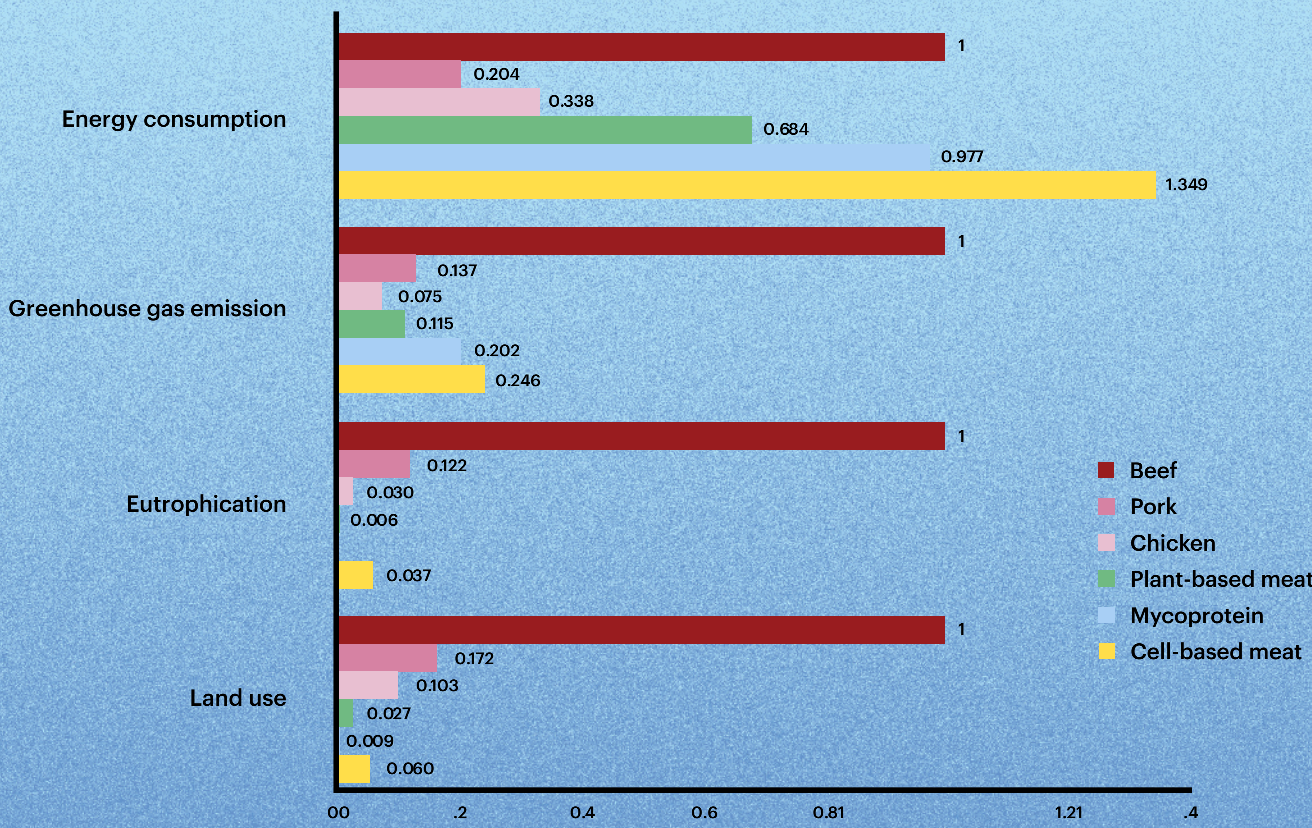


Figure 1. Comparison of the environmental impact of meat and meat analogs. Data are normalized to the impact of beef production. Eutrophication does not include data for mycoprotein. Land, emissions and energy data for mycoprotein were adapted from a 2015 LCA. Data for beef, pork, chicken and CBM were adapted from a 2015 life cycle assessment. Data for PBM were adapted from an impossible™ Beef LCA (land, eutrophication, emissions) and a Beyond Meat® life cycle assessment (energy use). Figure adapted from Rubio et al., 2020.

of heme may provide another solution to people's rejection of plant-based alternatives. As important as taste is, it's not the only component in the sensory experience of food. As Dr Bosworth explains, heme can be found in cows, and is utilised by meat substitution products to recreate the 'mameme aroma' experience, which can be so imperative to enjoying meat products.

Haemoglobin is the source of heme in cows, but can be replaced with sensational likeness by leghemoglobin in a food context. Leghemoglobin is found in the root nodules of soy and other legumes, and fixes nitrogen as soy plants grow. The two are oddly similar, which is why leghemoglobin has been appropriated for the purpose of mimicking 'blood' in plant-based foods.

There are many methods of accessing heme in leghemoglobin. The most intuitive one is digging up the roots of soy plants, and extracting the goodness inside for our purposes. However, this does seem counterintuitive if part of the aim is to be more sustainable – ripping up acres of crops for their roots doesn't quite fit. So, researchers found another way to produce leghemoglobin: fermentation. Again, our tiny microorganism friends help us battle climate change.

Fermentation for heme production involves using genetically engineered yeast, which has been inserted with the gene for leghemoglobin production (in soy, this gene is LBC2) [5]. The ancient process of fermentation then ensues, and a whole batch of yeast, working hard to produce leghemoglobin, is created. It is similar to the acellular agriculture process. After this, it's simply a matter of isolating the leghemoglobin produced, and adding it to whatever meat substitute a company desires.

Environmental psychology and the value-action gap

When we consider what we will be serving for our University reunion dinner in twenty years time, we may be leaning towards in vitro meats. Although a vegan diet offers many benefits, the sensory experience and cultural ties to eating food associated with emotions of satisfaction will remain [6]. When you know something tastes good, your taste sense works through chemosensory where a chemical stimulus on a nerve ending (taste bud) is mediated through taste and smell, and naturally our bodies like things that give us energy, such as sugars and carbohydrates [7]. We asked Dr Rosie Bosworth how future food developers considered this:

"When we think about food, future foods don't want to consider themselves as food tech or science start ups, especially when positioning themselves for the end consumer. By and large they still consider themselves as a producer of tasty food, that is the most important bit."

The cultural and sensory process of eating meat can be related to environmental psychology, modelled by the value-action gap [8] . Although we may be aware of the environmental and health benefits of eating less meat, there are stronger values such as convenience, habits, and satisfaction that result in continued meat eating behaviour. A 2021 New Zealand questionnaire found that an omnivore diet was the most prevalent dietary category (94.1%). Gender (men) and political ideologies (conservatism) predicted lower probabilities of transition from a meat to no-meat diet [1].

As climate concerns, food production demands and ethical tensions continue to grow it will be interesting to see which food technologies gain mainstream traction. This is where future foods such as cell-grown meats may come out as the top dish.

Stella Huggins - BSc/BA Biological Sciences, Psychology, Politics
Stella is a fourth year student of a BSc/BA conjoint majoring in biological sciences, psychology, and politics. Host/producer of a radio segment 'Tomorrow's World' on 95bFM, and a member of the Science Scholars programme, she is passionate about science communication.

Isla Christensen - MSc, Environmental Management
Isla is a Masters of Environmental Management student who is passionate about learning and sharing sustainable stories. Isla is researching how complex socio-environmental issues are discussed in the media and subsequently managed, with a focus on kauri dieback. Isla also co-produces a 95bfm segment 'Tomorrow's World'.

Inside the Hive: the Science Behind our Beloved Honey Bees' Evolutionary Behaviours

Ella Speers

Eusociality is a social behaviour observed across the Arthropoda and Chordata phylums that are characterised by reproductive division of labour, cooperative brood care and the overlap of generations. This complex and highly networked system has evolved over temporal and spatial scales to yield each individual within a colony a specific role to perform. In some species such as the beloved honeybees (*Apis* genus), helpers working underneath the reproductive queen never get to reproduce themselves, yet they care for new generations of young in the hive instead.

It would seem as if this organisation goes against the drive for life that the majority of organisms on the planet experience — to pass on their own successful genes to offspring; however, strong selection pressures have ensured that this phenomenon has become deeply rooted into some species' systems.

Honey bees have long been the focus of immense research efforts, so we now understand the intricate web of life inside the hive.

The research done on this species begs to answer the question as to why cooperation should exist in a world dominated by intense competition for the survival of the fittest [1].

Reproductive division of labour

A reproductive division of labour is one of the key elements in defining eusocial behaviour. If we start with a small-scale example, division of labour can be seen at the cell level where it is basal. Asymmetric cleavage during meiosis yields 'germ and soma' cell distinction — somatic cells serve only somatic function in the animal's body via mitosis, while germline cells produce the reproductive gametes. Despite both of these types of cells performing independent roles across time and space, their performance leads to the successful functioning of an entire individual as a whole.
This divisive mechanism where somatic and germline cells stayed together in the body after dividing was evidently successful enough to become established at the cellular level, and evolution has since propelled it further up the biological hierarchy — into species level.

As seen by the cells, multiple replicating entities remaining together after division forms a greater replicating system. At this higher species level, the division of labour is represented as multicellular organisation, of which stems eusocial behaviour.

In the case of our beloved honey bees, the multiple replicating entities can be seen as the bees themselves, the colony is the matter which they remain together in, and hence the hive becomes the entire replicating system.

The division of two castes inside the honey bee hive is fundamental to the significant success of the species. The morphologically distinct queen is responsible for colony founding, dispersal, and egg-laying while the workers perform tasks such as colony defence, nursing, and foraging in order to maintain the colony, yet do not reproduce themselves [2]. In order to keep this system successful in its operation and avoid the establishment of any individuals developing 'cheating' methods that enable them to reproduce, workers are morphologically constrained by a lack of functioning organs for sexual reproduction [3].

Today, eusociality takes the form of adult offspring remaining in the colony to help their mother reproduce; instead of doing so themselves [4].

Cooperative brood care:

Workers in the *Apis* genus who exhibit distinct morphological differences from their queen are restricted to only gaining indirect fitness by helping to rear related offspring. The colony's inclusive fitness is therefore a function of their reproductive output, with total offspring production depending on the quality of the queen and her mate, and of the cooperation of the workers. Much of the colony's social life therefore revolves around brood care [4].

The fitness benefits that honey bees inside the colony receive from cooperative brood care means that they continue to work in this system, despite seemingly going against the typical drive for reproduction as most species, including ourselves, experience. The division of labour employed by this species means that their own individual fitness is enhanced as it allows more efficient conversion of resources into reproductive capacity [7, pp. 368 - 373].

Overlap of generations as a causal factor for this behaviour

The high degree of social complexity observed in these colonies can be explained by the degree of close genetic relatedness from several overlapping generations. The social behaviour observed in honey bees is facilitated by a

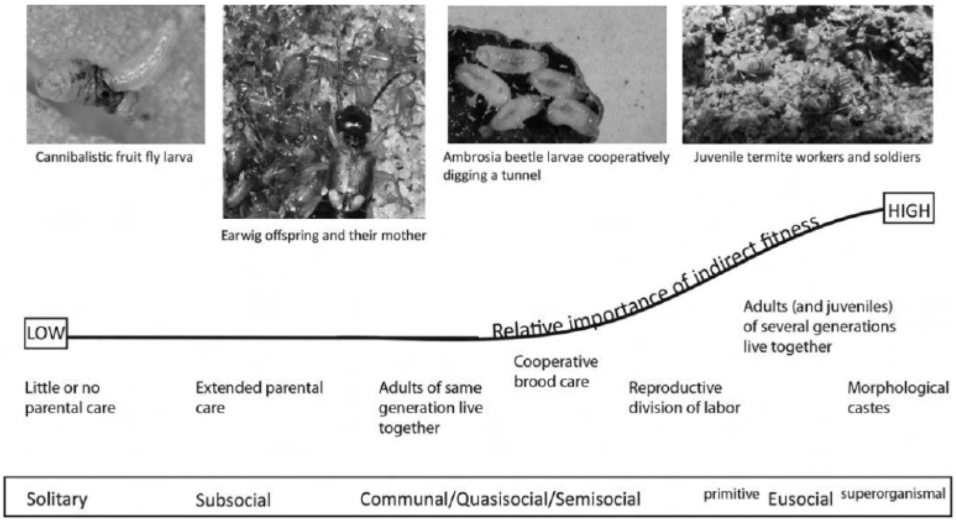


Figure 1. Insect sociality among a range of species, ranging from solitary insects (left) to completely eusocial (right). Indirect fitness becomes increasingly important throughout complexity as it is reflectant of the entire colony (Vijendravarma et al., 2017).

unique system of genetics known as haplodiploidy; a system in which females develop from fertilised diploid eggs, and males from unfertilised haploid eggs. The consequence of this is that the male passes on his entire genome to his offspring, while the queen passes on 50% of hers, meaning that offspring are 75% related to one another. This genetic system creates an irregular genetic asymmetry in which full sisters are more closely related to each other than a mother is to her own daughters [5].

As a result, the dynamicity of the whole colony changes due to increased levels of relatedness. Essentially, the fitness of an individual bee is based on the combined effects that its actions have on other individuals, weighted by their relatedness to that individual.

Thus selection acts to maximise inclusive fitness of the entire colony, albeit through a trade off between expending energy into a bee's own reproduction or investing in helping its relatives. The overall purpose of this behaviour is to increase the abundance of beneficial alleles present in the colony, which is directly beneficial for all individuals due to their high degree of genetic relatedness. This cooperative behaviour is known as altruism, and can evolve between related individuals over time and space. In altruism, a gene directs aid at other individuals who are likely to bear the same gene to itself despite the reduced offspring of its bearer [1]. From an evolutionary standpoint, we can understand that honey bee workers who rear their siblings are able to achieve maximal inclusive fitness when compared to individuals who reproduce themselves [5].

Using Hamilton's rule, we can understand how evolution selected for the loss of reproductive organs in worker bees, and instead favoured one reproductive queen. This rule is a theorem that acts as a foundation to predict whether social behaviour evolves under combinations of relatedness, cost, and benefit [6].

Hamilton's rule gives an equation to show when an organism should sacrifice their own reproduction in order to help relatives; given as $rB > C$, where r is the degree of relatedness between two individuals, B is the benefit to the recipient of the behaviour, and C is the cost of the behaviour to the individual giving the aid. C and B can be viewed as lifetime changes in the direct fitness [1].

Whether an organism should make this sacrifice or not depends on the value that is denoted by r. A gene for social behaviour is favoured by selective pressures if the sum of rB and C exceeds zero [1].

Honey bees have become one of the most successful insects on Earth due to their immense range span and establishment; and evidently their unique genetic system greatly contributes to this success. The honey bee colony arose through major evolutionary transitions that were dependent on cooperating entities finding a situation of inclusive fitness that kept them together for their own fitness benefit [1].

Today, these insects provide us with valuable resources and ecosystem services such as being key pollinators of our flora all over the planet. Perhaps next time you see a honey bee, think about the details of its hidden genes and how remarkable these are, as they allow for their widespread success and hence, ours too.

Ella Speers - BSc, Marine Science, Biological Sciences

Ella is a third-year student majoring in Marine Science and Biological Science. She is extremely passionate about counteractive measures against climate change, and marine ecology. Her area of interest is in restoration and conservation of marine habitats. She cannot wait to make a difference in fragile ecosystems.

Chimpanzees and Bonobos Have a Human-Like Understanding of Death

Katherine McLean

Chimpanzee mothers with infants. Image by Suju-foto from Pixabay.

Our understanding of what death and dying entail has long been viewed as one of the characteristics that makes humans unique [1-2]. This understanding is termed a "Concept of Death" (CoD). It is unknown how early in human evolution the CoD arose — whether it is restricted to our species or more widely present in primates [3-4]. I was interested in whether a comparative evolutionary perspective could shed light on this question. In a biological anthropological context, a comparative approach means utilising observation and analysis of living non-human primates to help differentiate between biological and cultural drivers of human behaviour. Since we are the only remaining member of our genus, *Homo*, comparative primatology helps determine what traits stem from our shared primate heritage and what is uniquely human. Suppose the CoD evolved early in our lineage. This could help contextualise ancient hominin behaviours, offer alternate explanations for findings in the fossil record, or even spur a rethink of the possibility of pre-*Homo sapiens* burials.

As part of a supervised research project, I utilised this comparative approach to investigate the CoD in our closest living relatives: the two members of the genus *Pan*. A CoD in the chimpanzee (*P. troglodytes*) and the bonobo (*P. paniscus*) would increase the probability that a CoD was also possessed by their last common ancestor with humans. This would then imply an early origin in our evolutionary story — perhaps associated with adaptations to increasing group size. Due to several factors, the most challenging being that death does not happen on command when you have a good project idea, I could not collect my own primary data. Instead, I was restricted to other researchers' opportunistic observations of *Pan* behaviours surrounding death. I thus collated and systematically reviewed decades of these videographic, written, and oral records. I analysed behaviours through a methodological framework I adapted from studies of the CoD in human infants and children. I found that chimpanzees and bonobos appear to have a simple but multifaceted CoD, including clear comprehension of death's biological characteristics and some understanding of its more metaphysical aspects.

Chimpanzee and Bonobo Social Behaviour

Sociality and relationships are intimately connected to aspects of social cognition such as the CoD. It is thus essential to have some basic knowledge of relevant chimpanzee and bonobo social structure and behavioural flexibility. The chimpanzee and bonobo both form large multi-male and multi-female groups that occupy specific territories [5-6]. Their everyday relationships can reach a depth of "bondedness" only found in reproductive pair bonds in other species [7]. Chimpanzees and bonobos regularly show intense interest in the genitals of their group members, with interactions often involving mutual genital inspection, smelling, and grooming [5,8]. Their interest in genitals is second only to their interest in each other's faces [9]. Both species have extremely hierarchical societies, although chimpanzees are more likely to reinforce their hierarchies with aggression and dominance displays [5,9]. Bonobos maintain more tolerant societies and utilise sex as a social tool for conflict resolution [10]. Mothers of both species are known to continue to carry their infants after death [8].

Subcomponents of the Concept of Death

The CoD in non-human animals has often been contested due to a lack of consistent definitions [2]. However, research on the CoD in children has a long and consistent history [11]. When assessing the development of the CoD in children, researchers break the CoD into seven subcomponents: 1) non-functionality (death means the cessation of bodily and mental functions); 2) irreversibility (once an organism is dead, it cannot be returned to life); 3) universality (death happens to, and only to, living things); 4) inevitability (death happens to all living things); 5) personal mortality (death will happen to me); 6) causality (what causes death); and 7) unpredictability (the timing of death cannot be known in advance) [12].

I consider inevitability and mortality to be sub-aspects of universality, as understanding death's universality implicitly comprises understanding that this includes yourself, a living thing, and excludes inanimate objects. I also consider causality and unpredictability a cognitive step beyond the fundamental CoD. Therefore, to investigate the CoD in genus *Pan*, I collapsed these seven subcomponents into only three: 1) non-functionality, being the understanding that death results in the complete cessation of bodily and mental functions; 2) irreversibility, being the understanding that once an organism is dead, it cannot be returned to life; and 3) universality, being the understanding that death also happens to others — this includes only living things and all living things, including oneself.

Behavioural Indicators of the Concept of Death

Research into the pace and pattern of the development of the CoD in human children relies on language and interviews [12-13], so I had to create non-linguistic behavioural equivalents for each criterion.

I recorded individuals as understanding non-functionality when they treated deceased group members' bodies in ways they never would when alive. These included incidences of post-mortem cannibalism and cases where mothers carried deceased infants in atypical positions that would cause injury if the infant was still alive, such as gripping in the mouth or dragging by a limb [16-20]. I also recorded individuals as understanding non-functionality when they performed deliberate checks for functionality, such as hitting the body [21], lifting and dropping limbs [8,16,19], sniffing genitals [22-23], or prying open the mouth to check for signs of breathing [8,21]. It must be noted here that an organism's understanding of non-functionality can only be as complex as their understanding of functionality, e.g., a chimpanzee cannot be expected to check for cessation of brain activity, as they do not understand this to be a necessary part of life.

That chimpanzees and bonobos ceased their efforts to wake or revive dead group members after receiving no response indicated that they understood death, unlike sleep, is irreversible. I also recorded individuals as understanding irreversibility when they exhibited strong emotional responses after receiving no indications of life. I observed a variety of such responses, including whimpering [24], screaming [25], rocking back and forth [8], tearing out hair [25], disturbed sleep [21], and refusal of food [8]. Some older female chimpanzees had gentler, although still emotional, reactions, such as grooming and cleaning the body or keeping overnight protective vigils [8, 21-23]. One unique indication of universality was seen after a group of chimpanzees who had earlier killed a rogue group member returned to the scene to find the body removed by human researchers [19]. When the group discovered the disappearance, they showed fear and made alarm calls, indicating they understood both that the dead cannot move and that this non-functionality is irreversible—the dead

Subcomponent	Verbal indicators in children	Behavioural indicators in chimpanzees and bonobos
Non-functionality	Answering "No" to a variation on "Can a dead thing do x?". X could be physical, like breathing or walking, or mental, like thinking or feeling [14]-[15].	Treating deceased bodies in ways they never would if alive; post-mortem cannibalism; deliberately checking for functionality and signs of life.
Irreversibility	Answering "No" to questions such as "Can a dead person come back to life?" and answering "How can you make dead things come back to life?" with some variation of "You cannot" [13].	Stopping efforts to revive after receiving no response; strong emotional reactions to death; deliberate disposal of bodies.
Universality	Answering "Yes" to questions regarding the death of other living things, such as "Will x also die one day?". X can be the child, another person, an animal, or a plant [13]-[15].	Reacting to death in other species; showing increased caution and care for themselves or their loved ones.

Image by Sasint from Pixabay.

should not suddenly return to life, get up, and walk away.

I found behavioural indicators of universality much harder to identify, as this subcomponent is less about an organism's immediate reaction to a death, which can be observed, and more about a mental transference of that death's implications to future situations. One incident that may indicate a rudimentary understanding of universality occurred after a mother chimpanzee lost an infant to illness [26]. She became overly attached to her remaining child, a six-year-old, and began treating him like a baby — carrying him on her back, hand-feeding him, and sharing her night nest with him — as if she were afraid he too might die. Reacting to the deaths of other species can also indicate some degree of universality, as the individual is showing they can apply their understanding of death more broadly. A group of chimpanzees who encountered a dying baboon became very agitated — making alarm calls and sniffing, stroking, and grooming the body [9, 24]. Both chimpanzees and bonobos were also observed acting differently towards snakes after their death. They let infants and juveniles use the bodies as toys, rather than exhibiting their usual fear and avoidance [8-9]. I was hoping to find evidence of individuals who witnessed an accidental death becoming increasingly cautious when later navigating the same dangerous environment, indicating an understanding that the same death could happen to them. However, the opposite was observed: after seeing a group member fall and break his neck, a second chimpanzee almost fell himself when vines gave way beneath him [24]. He showed no extra caution despite his group member's death just hours earlier.

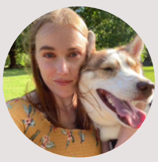
Chimpanzees and Bonobos Understand Death

When I brought these disparate incidents and behaviours together, it became clear that chimpanzees and bonobos have a complex CoD, including a cogent understanding of the biological subcomponents of non-functionality and irreversibility and at least some degree of comprehension of the more metaphysical subcomponent of universality. There is abundant evidence for non-functionality and irreversibility: chimpanzees and bonobos deliberately examine bodies for signs of life and have strong emotional reactions, analogous to grief in humans, upon receiving no response. In no case did I note a chimpanzee or bonobo continuing their efforts to wake or revive a body for any significant period after receiving no response. Adolescents and juveniles were seen to investigate bodies the longest, whereas older group members, who have likely encountered death before, interacted with the dead for a far shorter time. This difference suggests that the Pan CoD is learnt, rather than innate, and thus close in nature to the human CoD, which is developed via experience and teaching. However, I did not find satisfactory evidence of universality in chimpanzee or bonobo behaviours. This was unexpected, as universality is the first of the three core subcomponents to develop in human children [12]. It is possible that universality may have been absent from my data due to behaviours imperfectly reflecting underlying thought processes and not due to an absence in cognitive capacities.

Shared Origins of the Human and *Pan* Concept of Death

One common thread in my research was that the individuals most affected by each death were those emotionally closest to the deceased. One chimpanzee, who died of illness, was a highly social individual who spent time with many different subgroups — accordingly, most of the group was interested in and interacted with his body [23]. Even then, the two individuals most affected were his closest friend, who visited his body more than any other male, and his adoptive aunt, who groomed his body, cleaned his teeth, and kept vigil after everyone else had long since left. Conversely, after the death of a low-ranked and socially peripheral female, the only group member to spend any time near the body was her daughter [27]. Infants are also socially peripheral, having not yet formed any social networks. Unsurprisingly, in cases of infant death, only the mothers had any noticeable emotional response [8,16,22]. *Pan* behaviours around death appear to be simply a translation of the bonds created in life.

The *Pan* CoD also appears to be more of an emotional reaction than categorisable behaviour. Many scholars criticise anthropomorphism, but I believe that anthropodenial, or the rejection of similarities between humans and our close relatives to keep us on an evolutionary pedestal [8], is worse. If two closely related species act similarly under similar circumstances, it is reasonable to theorise that they are similarly driven. Therefore, I describe this emotional response to death as grief, and the behaviours that stem from it, such as grooming and keeping vigil, as mourning. In humans, grief is an emotion, a feeling of sorrow caused by distress over a loss, with mourning then being the social behaviours exhibited in response to that grief [28]. As the *Pan* CoD appears rooted in grief and mourning, it is reasonable to term it a socially driven phenomenon. This may help to contextualise behaviours throughout the hominin family tree. The socially driven CoD seen in chimpanzees, bonobos, and humans likely evolved as an adaptation to protect against destabilisation caused by death. The more communal a species, the more effort is needed to protect against social destabilisation. Chimpanzees and bonobos, like humans, are highly social animals to whom a defined hierarchy is vital for stability. Death impacts social groups by severing bonds, thus creating a rupture in the social fabric: the most gregarious animals have the most mourners as they had numerous strong bonds in life. The CoD evolved because it is needed to function as a social stabiliser. If a species develops the ability to understand death, then they can feel grief. If a species can feel grief, then they can begin to mourn. If a species can mourn, then they can more quickly re-categorise the living to dead, reform the social structure, and shape a new dominance network after death has left a hole in the hierarchy.



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Are We Alone in the Universe?

Lucas Tan

Arthur C. Clarke, a science writer and futurist, once said, "*The idea that we are the only intelligent creatures in a cosmos of a hundred million galaxies is so preposterous that there are very few astronomers today who would take it seriously. It is safest to assume, therefore, that they are out there and to consider the manner in which this fact may impinge upon human society.*" The universe is approximately 93 billion light-years in diameter and is expanding at roughly 1.96 million km/s [1]. In other words, when travelling at the speed of light (approximately 3 x 108 m/s), it would take an individual 93 billion years to travel across the universe. Many people are curious as to why we still have not encountered extra-terrestrial (ET) life, despite the boundless possibilities that exist within the vast expense of the universe. This is also known as the Fermi paradox, which describes the conflict between expecting a high probability of the existence of intelligent life elsewhere in the universe compared to the 'empty' universe we observe [2]. Another term used to describe this silence and loneliness we are experiencing is the 'Great Silence' [3].

Scientists have pondered the existence of ET life for centuries. In 1961, astrophysicist Frank Drake developed an equation — the Drake equation — that seeks to determine the potential number of intelligent civilisations in our galaxy (Table 1) [4]. However, many sceptics claim that the equation relies on too many assumptions and that the actual number of intelligent civilisations will more likely than not vastly differ from our predictions. Furthermore, scientists have proposed modifications and novel approaches to the original equation in recent years [5-7]. This article explores a few of the many proposed theories as to why we have yet to encounter ET life.

The Great Filter

Despite the universe being incredibly ancient, we do not have any solid evidence of ET intelligence colonising our solar system or nearby systems. R. Hanson [7] suggests that a 'Great Filter' stands between ordinary dead matter and advanced life that flourishes. For humans to thrive as a species like we are now, the appropriate conditions had to be present at the right time. It has been an arduous journey from the formation of our star system to the first ribonucleic acid (RNA). This subsequently led to the establishment of single and multicellular life and to the birth of complex organisms that utilise tools. Between each 'checkpoint', there are multiple ways in which the suitable conditions could have been absent, leading to our inexistence. Evolution is a complex biological process that — until the publication of Charles Darwin's *On the Origin of Species* — we did not comprehensively understand [8]. Perhaps there are microorganisms somewhere out in the universe, but the probability of such organisms evolving into intelligent sentient beings is infinitesimal.

Another suggestion that has been made concerning the Great Filter is that sufficiently developed civilisations eventually eliminate themselves, rendering the species extinct with no traces of them left behind. Kardashev, N. S. [9] introduced a scale to classify technologically advanced civilisations according to the amount of energy they consume. Decades since, extended versions of the Kardashev have been suggested (Table 2) [10]. A Type I civilization is able to fully harness the energy that reaches its home planet from its parent star [9]. Basalla G. [11] claims that we are not a Type I civilization yet as we are unable to capture all the radiant energy streaming down on Earth. Our present civilization is closer to a Type 0.7, and scientists have predicted that we will attain Type I status by 2347 [12,13]. As a Type 0.7 civilisation, we already possess weapons of mass destruction that can destroy the Earth multiple times over. A moment of selfishness and carelessness could send us down a rabbit hole. As a species, we are also battling climate change. A new report generated by the United Nations (UN) mentioned that we must act now and reduce carbon emissions before we tread on an irreversible path toward climate disaster [14]. Climate

Table 1

$$N = R_* \cdot f_p \cdot n_e \cdot f_1 \cdot f_i \cdot f_c \cdot L$$

N = Number of civilisations in our galaxy in which communication is possible

R_* = Average rate of start production

f_p = Fraction of stars with planetary systems

N_e = Number of planets per solar system that can potentially support life

f_1 = Fraction of suitable planets on which life actually appears

f_c = Fraction of civilisation that develop a technology that produces detectable signs of their existence

L = Average length of time such civilisations produce such signs (years)

Table 2

Type	Civilisation Title	Power Harnessed (W)
0.0	Biological	10^{6}
1.0	Planetary	10^{16}
2.0	Stellar	10^{26}
3.0	Galactic	10^{36}
4.0	Observable Universe	10^{46}

change can lead to detrimental health outcomes; worse still, due to the unprecedented rate at which glacial ice is melting, thousands of microbes are now being released and reactivated into terrestrial and aquatic environments, which can lead to epidemics or even pandemics [15,16]. The Great Filter is a fantastic hypothesis for why we may not have encountered ET life. Recklessness and ignorance could have led to the fall of once glorious civilisations, preventing us from ever discovering their existence.

The Zoo Hypothesis

In 1973, John A. Ball proposed the Zoo hypothesis [17]. The hypothesis posits that intelligent life avoids interacting with us on purpose and that — like how we keep animals in enclosures and view them from a distance — they view the areas we reside in like a zoo. As a result, we will never discover ET life as they want to remain hidden from us, and they possess the technological capabilities to ensure it remains so [17]. The Zoo hypothesis is somewhat similar to the 'Prime Directive' — the belief that every society has the right to unimpeded and natural development — in the famous series Star Trek [18]. Much of the Zoo hypothesis is about respecting the autonomy of other civilisations, allowing infant civilisations to pursue their own destiny without interference. There is a possibility that advanced civilisations millions or billions of years older than us are watching us from the sidelines, waiting for us to achieve what they would consider intellectual, social and technological maturity. However, the concept that incredibly advanced beings are interested in the natural evolution of life on Earth sounds a little self-centred [19]. From an anthropocentric standpoint, we have never been great at non-interference with populations of other lands and differing cultures. Why should we assume that, unlike us, other civilisations are peaceful and altruistic? The Zoo hypothesis assumes that other civilisations care about our natural development. The contrasting proposal to this is that we are simply not worth contacting.

We Are Not Worth Contacting

When considering the age of the universe, we are an extremely young civilisation. To put this into perspective, scientists use the Cosmic Calendar, which compresses the timeline of the universe's birth to our current time of technological development and globalisation. Based on this framework, with the Big Bang occurring on the exact first second of New Year's Day, the first humans only appeared on December 31, at approximately 22:30. Agriculture was only invented by humans on December 31, at 23:59:20 [20]. The cosmic calendar demonstrates how insignificant our species is on a grand scale. Over the billion years in which the universe has come into existence, there could have been civilizations that are more than a thousand-fold more advanced than us. Like how we would not teach bacteria calculus, ET life may not find contacting us worthwhile. It is undeniable that we have made great strides in many aspects ranging from technological developments like smartphones and aeroplanes to scientific breakthroughs like the ability to edit our genes, amongst others. However, one must acknowledge that many social and scientific problems still exist. There are more than 20 ongoing military conflicts worldwide due to civil wars, territorial disputes and transnational terrorism [21]. Furthermore, there have been increasing inequalities in areas such as health and wealth, and many debilitating diseases still plague the population worldwide with no cure. As a species, we have much to learn and discover. Our lack of knowledge and wisdom, compared to potential ancient ET civilisations, may be why we have yet to encounter ET life.

Communication Differences

There are approximately 7,151 human languages spoken today [22]. When considering methods of communication the millions of species of animals worldwide use, we end up with a manifold of communication methods. The dolphin, for example, communicates through three known types of acoustic signals: burst-pulsed sounds, echolocation, and frequency modulated whistles [23]. Life on Earth alone communicates through a multitude of modalities. While we have sent and received many signals to and from space, we still have never directly interacted with ET intelligence. Current scientists involved in the Search for Extraterrestrial Intelligence (SETI) attempt to communicate with ET life by relying on the assumption that the basic principles of chemistry, mathematics and physics hold true throughout the universe [24]. This assumption may be wrong, and other scientific principles could govern the environment in which ET life thrives. Another challenge to communicating with ET life is the time it takes for civilisations to receive signals from other life forms. For example, a radio signal we have received from 12 million light-years away would mean that an ET civilization sent the signal toward us 12 million years ago. By now, the civilisation that sent said signal could have destroyed themselves or would have become so advanced that they have decided not to contact us. Similarly, we could send a signal into space now, and if a civilization one million light-years away receives it far into the future, we may have been long gone. Another interesting thought experiment is that ET life who look through a telescope — that must be technologically capable beyond human comprehension — would not see the technological progress we have made. If an ET species from 65 million light-years away looked at Earth through their telescope, they would see dinosaurs roaming around. There would then be no incentive in exhausting resources to travel to Earth and interact with life here.

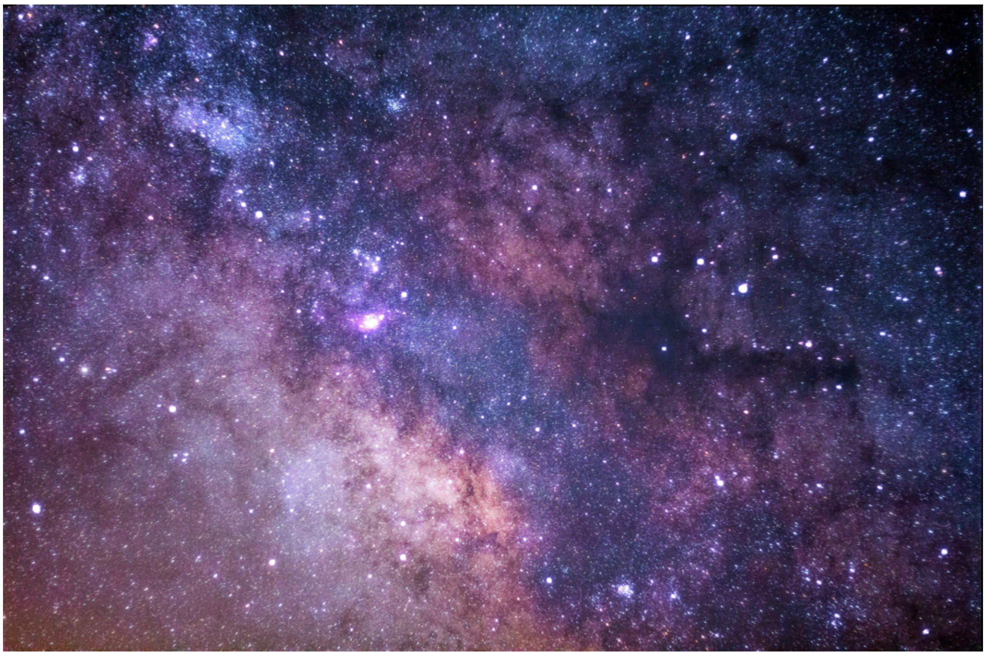

Image by StockSnap from Pixabay

To conclude, there are many suggestions made as to why we have not encountered ET life, most of which are plausible. Could we indeed be alone, or are the technological barriers to cross for interstellar interaction simply too high for us now? Even if we discover ET life over the next few centuries, there are multiple implications to consider. Fundamentally, our worldview will evolve. ET life will probably be vastly different from what most people expect them to be — green figures with large round eyes, or other cinematic representations of ETs. Whether the vast universe we reside in has other life forms remains to be seen.

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Closing Comments

That concludes yet another issue of *Scientific*. It's always a bittersweet page for us. We'd like to say an enormous thank you yet again to our talented group of guest writers, we appreciate the sharing of your passion and knowledge more than you know. Another thank you to our dedicated executive team who contributed an article this edition, and to the rest of the team who consistently prioritise the mission of the publication.

In the time between our last issue and the one that you're holding, we held a science communication workshop with Auckland University Women in Science, where two fantastic speakers gave up their time to share their experiences in science communication as a field. We'd like to publicly express our gratitude to Scott Pilkington and Paul Panckhurst for their invaluable insights.

We've been working behind the scenes with a number of wonderful organisations to bring you updated perspectives on scientific issues, and the possibility of events in the future. Stay tuned into our social media for more information on that in the future. Also, keep having a go at our Instagram quizzes – they certainly keep the exec team entertained.

Ngā mihi nui,
Stella Huggins, President for UoA Scientific 2022

Corrections

In the previous Issue 1, Volume 2, in the article *The Ecology of Undesirable Organisms,* it is stated that adult wasps do not eat insects. However adult social wasps (Vespidae) do eat insects and arachnids. Solitary wasps do not eat insects.

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I'm a magazine, but I have feelings too. Don't throw me away!