



INVISIBLE YOU

THE HUMAN MICROBIOME

'I am large, I contain multitudes.'

Walt Whitman, *Song of Myself*.

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INVISIBLE YOU

THE HUMAN MICROBIOME

We are not alone.

Our bodies contain ten times as many microbial cells as human ones.

These 'communities' in and on our person are, in the main, essential.

They help form us, feed us and protect us and maybe more besides.

Welcome to Invisible You.

Invisible You tells the story of the Human Microbiome; the community of microorganisms that we share our body with. Supported by the Wellcome Trust, the exhibition explores human and planetary health in a rapidly changing world.

eden project

The Eden Project, an educational charity, connects us with each other and the living world exploring how people can work together and with nature towards a better future.

Fifteen years ago we planted a global garden in a disused china clay pit as a symbol of regeneration. In this Living Theatre of Plants and People we reconnect our audiences with nature, immersing them in global ecosystems: one Biome houses the largest rainforest in captivity, another the landscapes and crops of the Mediterranean regions. These massive bubble-shaped conservatories serve as a backdrop to the Outdoor Gardens, growing the crops and landscapes of our own temperate climate.

Until now, one vital ecosystem has been missing: our own. Invisible You, the Human Microbiome, takes you inside the body to meet the community of microbes that nurture you. Will exploring and understanding our microbiome help us lead healthier lives? Can we draw any parallels with regard to how we nurture the global ecosystem?

The Eden Project is an educational charity, registered charity number 1093070 (The Eden Trust).

www.edenproject.com

Supported by
wellcometrust

The Wellcome Trust is a global charitable foundation dedicated to improving human and animal health. They support the brightest minds in biomedical science, the humanities and the social sciences, as well as education, public engagement and the application of research to medicine.

‘The huge impact that the human microbiome has on health is becoming clearer and clearer. Invisible You is a fantastic project that will allow access and insight to the science and research behind our understanding of our own internal ecosystem, through the medium of art. The Trust has a long history of supporting high quality collaborations that help artists, scientists and the public to engage with complex issues that affect human health, and we’re delighted to be able to help bring a topic this compelling to a venue as unique as the Eden Project.’ – Tom Anthony, National Programmes Adviser, The Wellcome Trust

www.wellcome.ac.uk

mi•crobe

n. ('maɪ.krəʊb/kroub)

A very small living thing, that can only be seen with a microscope.

mi•cro•bi•ome

n. (maɪ krou'baɪ oʊm)

Biology. The totality of microorganisms and their collective genetic material present in or on the human body or in another environment.

Coined in 2001 by Joshua Lederberg, molecular biologist.

micro(be) + biome

Our microbial world

Along with other humans, plants and animals, we share the planet with trillions and trillions of life forms invisible to the naked eye. More would fit in a teaspoon of soil than there are people on the planet.

They are, in the main, beautiful. They are, in the main, essential.

Microbes have been around for about 3.5 billion years and are vital cogs in the cycles of life. They are the ultimate recyclers (rotting stuff and fertilising our soils), they help raindrops to form and wind to blow, they clean our air and water and help make our foods. There would be no cheese, chocolate, bread or beer without our invisible assistants.

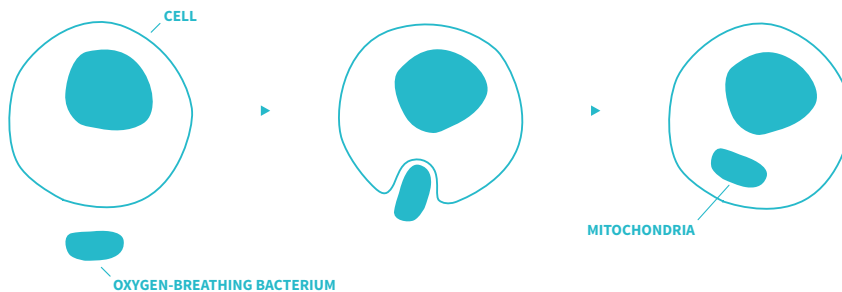
They form vast communities, food webs and hierarchies. They talk with each other and have similar systems to our visible world but on a completely different scale.

If we discover life in 'outer space' it will probably be microbial.

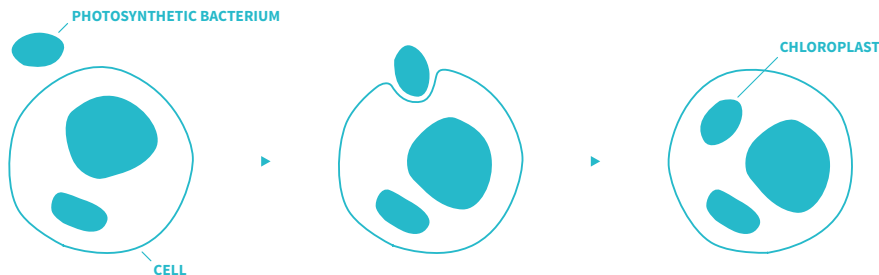
Evolution

Microbes were the first life forms to evolve around 3.5 billion years ago. They have been evolving ever since. They are everywhere around us, on us and in us.

It is believed that elements of eukaryotic cells (the cells of humans, animals, plants and fungi) were once prokaryotic (bacterial) cells.



Some oxygen-breathing bacteria were enveloped by bigger cells and became mitochondria, found in all eukaryotic cells today. They use oxygen to break down carbohydrates to release energy and give off carbon dioxide and water.



Some cyanobacteria (photosynthetic bacteria) were enveloped by bigger cells too and became the green 'chloroplasts' found in plant cells. They capture sunlight and turn it into a battery of energy (carbohydrate, a sort of sugar) using carbon dioxide and water as raw materials. Their waste product? Oxygen. Ah, the cycle of life.

Who's who

Eukaryotes

Includes all multicellular organisms and some single-celled organisms.

- Cells contain a nucleus and organelles (that do organ-like functions)
- DNA in chromosomes inside the nucleus
- Bigger than prokaryotic cells

Prokaryotes

Include **bacteria** (single-celled microorganisms with cell walls) and **archaea** (similar in size to bacteria but with a distinct evolutionary history and biochemistry).

- Cells have no nucleus or organelles
- Their DNA is free inside the cell (not in a nucleus)
- Smaller than eukaryotic cells

Viruses

- Evolved outside the tree of life (as they can't reproduce on their own)
- Smaller than bacteria
- Comprise DNA or RNA in a protein coat
- Only able to multiply when they insert their DNA/RNA into the living cell of a host





CUT MICROBE

Rogan Brown

Handcut paper

Microbes generally have a bad press. In reality, many are not just essential, they are also beautiful.

This paper sculpture is based on a single cell bacterium, *Escherichia coli*. *E. coli* are frequently found in the gastrointestinal tract of humans and other warm-blooded animals. They are responsible for the production of Vitamin K amongst other things. Most types live in the gut quite harmlessly but other strains can cause illness. They are one of the most widely studied bacteria and have helped our understanding of the microbial world.

Delicate, fragile layers of fine white paper form a relief drawing creating a shadow play, highlighting the intricacy of the patterns. The slow, meticulous process of cutting is as important as the finished piece: the act in itself a reflection of the complexity of Nature.

Rogan Brown is an artist whose work explores the boundaries between observational study and artistic interpretation. Somewhere between scientific accuracy and unbridled imagination, his pieces explore natural phenomena at different scales, from individual cells to large geological formations.

www.roganbrown.com

*‘If you don’t
like bacteria,
you’re on the
wrong planet.’*

Stewart Brand, writer.

THE SECRET LIVES OF BACTERIA

News and Views from the Science Advisory Group – Dr. Michiel Vos

Our knowledge of ecology and evolutionary biology has mostly originated from animals and plants. Bacteria lead their lives largely hidden from our view and in ways that seem fundamentally different to us. Perhaps the most striking feature of bacteria is their astounding metabolic diversity. Animals breathe oxygen to turn plants (or other animals that eat plants) into energy and building blocks. Many bacteria do the same, but others digest their food by ‘breathing’ sulphate or some compounds that humans prefer not to ingest. Other bacteria use photosynthesis or creatively mix different types of metabolism. Many bacteria can withstand extreme conditions, with some growing at temperatures above 100°C, at a pH close to zero or in brine ten times saltier than seawater. This versatility has allowed bacteria to colonize almost every spot on our planet, from plant leaves to cracks in rocks five kilometres below the earth’s surface, from hydrothermal vents on the sea floor to the depths of your bowels. Bacteria make a living underneath kilometres of ice, control cloud formation, provide counter illumination in the bellies of stealthy squid, and help to produce delicious kimchi.

Besides being vital to our own health and wellbeing, bacteria are crucial to the earth’s biogeochemical cycles. One example is the nitrogen cycle. The element N is key to all life, forming part of DNA and proteins. Although our atmosphere consists of 78% of dinitrogen (N_2) gas, this form of nitrogen is not readily biologically available, limiting plant growth and ultimately all other life. For atmospheric nitrogen to become available, it

has to be fixed into ammonium compound NH_4^+ . This is where a wide variety of bacteria step in. Some bacteria trade their hard-won nitrogen with plants or fungi for other compounds and shelter. The most well-known example of such symbiotic bacteria is *Rhizobium*, housed in the root nodules of legumes. Farmers exploit this nitrogen fixation capability by using legumes in crop rotation to replenish soil nitrogen levels.

Bacteria do not only fix nitrogen to soluble ions and organic molecules, but they also convert these compounds back to dinitrogen (N_2) gas. A completely novel way of doing this was discovered as late as in the 1980s, termed the ammonox process. Painstaking isolation experiments yielded a variety of bacteria able to perform this reaction (painstaking because the doubling times of anammox bacteria are over a week, compared to less than half an hour for *E. coli*). This discovery completely changed our understanding of the nitrogen cycle. Importantly, anammox-based reactors are proving to be hugely promising in efficiently removing ammonium compounds from waste water, turning them back into dinitrogen.

Dr. Michiel Vos is a lecturer at the European Centre for Environment and Human Health at the University of Exeter Medical School.

'You are 99.99% identical in terms of human DNA to the person sitting next to you. This is not true of your gut microbes. You might only share 10% similarity to the person sitting next to you ... That's as different as this prairie and this forest.'

Dr. Rob Knight, University of California, San Diego.
From *Ted Talk*, 2014.

genes 100:1.

ON YOUR SKIN

Skin, our largest organ, is on average home to about 1 million bacteria for every sq cm.

Some are responsible for the odours in different body parts. They convert our sweat to foul-smelling compounds or to potent 'pheromones' - chemicals that help attract a mate.

IN YOUR MOUTH

The front door for microbes contains many environments (teeth, crevices, cheeks, gums, tongue) and many communities. From air-lovers(aerobic) to air-haters(anaerobic), and from protectors (against dangerous microbes) to bad breath makers.

Teeth (unlike other body parts) do not 'shed', so microbes hang out and form cities, towns, tower blocks and villages. So don't forget to brush them.

UP YOUR NOSE

Many different species live here without any issue but some can cause disease when our immune system is weakened.

For example, *Staphylococcus aureus* can cause boils, impetigo and food poisoning and *Streptococcus pneumoniae* can cause pneumonia and meningitis.

DOWN YOUR THROAT

Loads of them: *Corynebacterium*, *Neisseria*, *Mycoplasma*, *Staphylococcus*, *Streptococcus* and *Haemophilus* species. Some, on occasion, can turn nasty (pathogenic) e.g. *Streptococcus pyogenes* (strep throat or laryngitis).

IN YOUR GUTS

Your large intestine contains most of your microbiome; about 1000 different species which weigh just over a kilogram. The same sort as in the person you are specific to you.

Home sweet home

We share our body with around 1,000,000,000,000,000 microbes. They outnumber our own cells 10:1. That makes us human-microbe hybrids. If you took the microbes out of your body and popped them on the scales they would weight about 1.5-2kg (about the same as your brain).

The popular understanding that microbes only cause illness is being eclipsed by an emerging picture of far greater complexity. First we saw them under the lens, then we realised some harmed us, so we killed them (sometimes indiscriminately). Now we know that some are just freeloaders and many are predominantly useful.

We play host to around 2,000 different types (i.e. species) each living on and in different parts of us. They form extremely dynamic populations, interacting with each other, performing different roles, helping to form us, feed us and protect us and maybe even affecting our mood, weight, intelligence and personality.

The landscapes of our lives

Microbes live on our skin, inhabit every orifice, surround our words and share our kisses. They form living communities in the landscape of our body with its contours of hills, valleys and landmarks – ears, eyes, nose, toes, armpits, belly button, vagina, mouth, lungs and guts – and climatic zones – from the warm, dark armpits to the dry desert of the forearm and the clear, cool eyes to the moist cave of the mouth.

Our body is an ecosystem = ‘a biological community of interacting organisms and their physical environment’, just like a rainforest, just like our Biomes.

Microbes form us

Developing in the womb we are microbe-free. During birth, we are coated with microbes as we pass through the birth canal. These are soon joined by microbes from first touch, first kiss, mother's skin, mother's milk, others' touch, air, clothes, sheets ...

These microbes help our newborn bodies work out which cells to make into what, help develop blood capillaries, produce enzymes and digest our food, including our very first meal. During pregnancy, the mother's microbes shift their net metabolism so that more calories flow from food to her body. *Lactobacillus johnsonii*, which we pick up in the birth canal and from our mother's skin and milk, digests our mother's milk for us (because we can't).

Microbes also help the development of our immune systems. In our first two years it's a bit of a tradeoff while our immune systems develop and work out how to distinguish the desirable from the non-desirable microbes. Research suggests the microbes themselves have a hand in this.

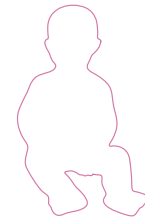
Microbes feed us

We are a tube with an entrance (mouth) and an exit (anus) so our gut is, biologically speaking ... outside our bodies. There are more microbes in the lower gut than anywhere else: about 1,000 different species layered an inch thick. The microbes in our GIT (gastro-intestinal tract) feed us. They generate around 10% of our energy needs, produce enzymes to digest food, break down tough plant materials and provide vitamins (folic acid, vitamins B and K and nicotinic acid). They regulate fat storage, make essential amino acids (protein building blocks), help us absorb iron among other things and help make gut cells (food absorbing and antibody producing).

The microbes in our GIT vary from person to person. Malnutrition is not just about what we eat, but what types of microbes we have in our gut. Microbes in the guts of people in vitamin-hungry parts of Malawi can extract more vitamins from food than microbes in the guts of people with vitamin-rich diets in North America. Fat and thin people have different microbial communities too and different diets can change the types they have.



Throughout our lives our bodies are covered in microbes – well, almost. In the womb we are microbe free – 100% human.



By the time we are two, and on into adulthood, our microbial cells outnumber our own cells 10:1; our microbiomes are fully formed –and they have their work cut out.

Microbes protect us

Many beneficial microbes stick, stay and protect.

Gatekeepers:

They exclude the unwanted, stand firm and crowd others out. They form skin barriers, cleaning, moisturising and protecting. They colonise and guard the mucus-lined bits at the entrance to the passageways (e.g. up the nose, in the mouth...).

Protectors:

They chase and fight off the undesirables using chemical warfare, make places 'unsuitable' for the undesirables and help protect us from auto-immune diseases.

Cleaners:

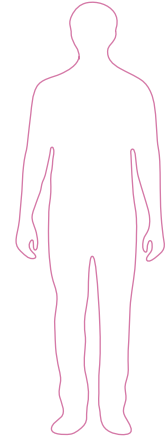
Some microbes detoxify some of the harmful/poisonous things we've eaten.

Builders:

They help build our 'immune cell-making factories' (most of which are in the gut) and help our immune cells reproduce.

Teachers:

They help train our immune system in what to accept or reject (by chemical and shape recognition) and provide instructions to 'trainer immune cells' so they recognise and don't attack friendly microbes.



As we develop, our microbiome is influenced by our ancestry, where we live, who we live and interact with, what we eat and where we go.

When we die, our bodies stop working, our immune systems stop working. The microbes take over.

THE HUMAN SUPER-ORGANISM

Anna Dumitriu & Alex May

Digital installation

The complex array of microbes that live on our bodies is usually invisible to the naked eye. This interactive installation allows participants to visualise the diverse communities of bacteria that live on their skin. Viewers are invited to place their hands onto a 'virtual Petri dish' triggering hundreds of tiny microscopic colonies to grow following the forms of the fingers and palms. This challenges viewers to re-evaluate their notions of clean and dirty.

The digital installation is made using custom software written in C++ and uses sensor technology to track the hands of participants as they touch an interactive screen. The resulting 'virtual Petri dish' images are generated in real time for each participant from a library of high definition time-lapse films made by the artists using DIY microbiology techniques.

Anna Dumitriu is an artist working at the forefront of art and science collaborative practice. Her installations, interventions and performances use a range of biological, digital, and traditional media, in particular bacteria.

www.normalflora.co.uk

Alex May's art practice explores the boundaries between human perception and digital technologies. He works with code, video projection and interactive technologies.

www.alexmayarts.co.uk







SYMBIOSIS

Rebecca D. Harris

Embroidered textile

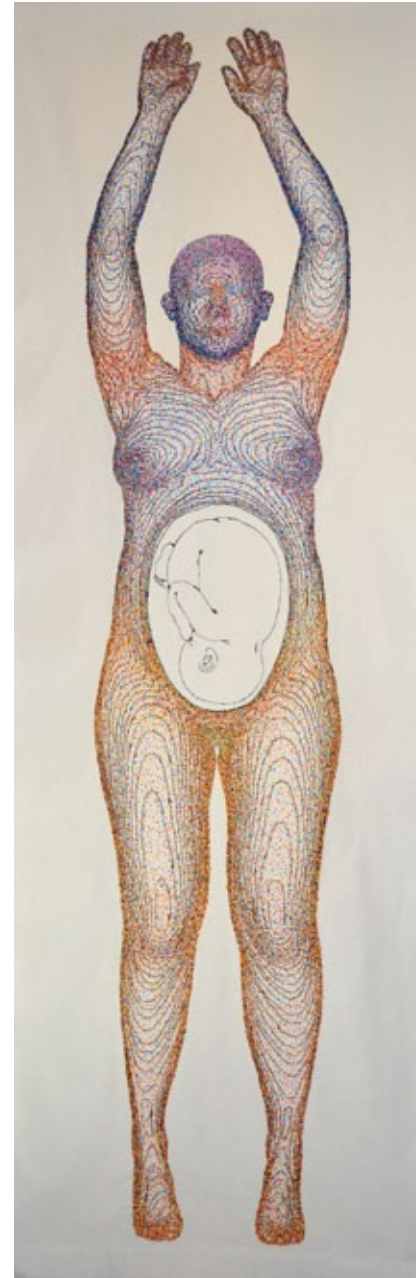
Human microbiome research often refers to our community of microbes as an ecosystem.

This embroidered textile uses the analogy of the body as a geographical area. This idea is brought to life by depicting a woman's figure using contour lines, inspired by those found in cartography and medical MRI scans. Upon this terrain are charted areas of trillions of microbes that live on our bodies, represented as hand-embroidered French knots.

The different colours represent the major groups of microbes present on the skin, and give a sense of the diversity, proportions and distributions of the communities that make our bodies their home. The foetus is microbe free and quietly awaits its journey into the world for its first seeding of microbes. The bright, seductive and tactile surface is embellished rather than blemished, a means to focusing on the positive aspects of our human microbiome.

Where textiles are used to conceal, Rebecca D. Harris uses them to reveal. Her work investigates how the body is perceived medically and socially through the medium of textiles.

www.rebecca-harris.com



GIT

Paul Spooner

Automata

Long before the evolution of animals with backbones there were Gastrointestinal Tracts (GITs). Some of our ancestors were simply tubes without legs, fins, flippers or any other means of locomotion. They had to wait for their food to be delivered, washed into their top holes and out of their bottom holes. We differ from these life forms in that we can go out into the world to get our own food but the objective is the same: to support life we must extract energy from material passing through our GITs.

Every GIT contains billions of microorganisms. They are a crucial part of the system, intrinsically linked to many of our inner workings.

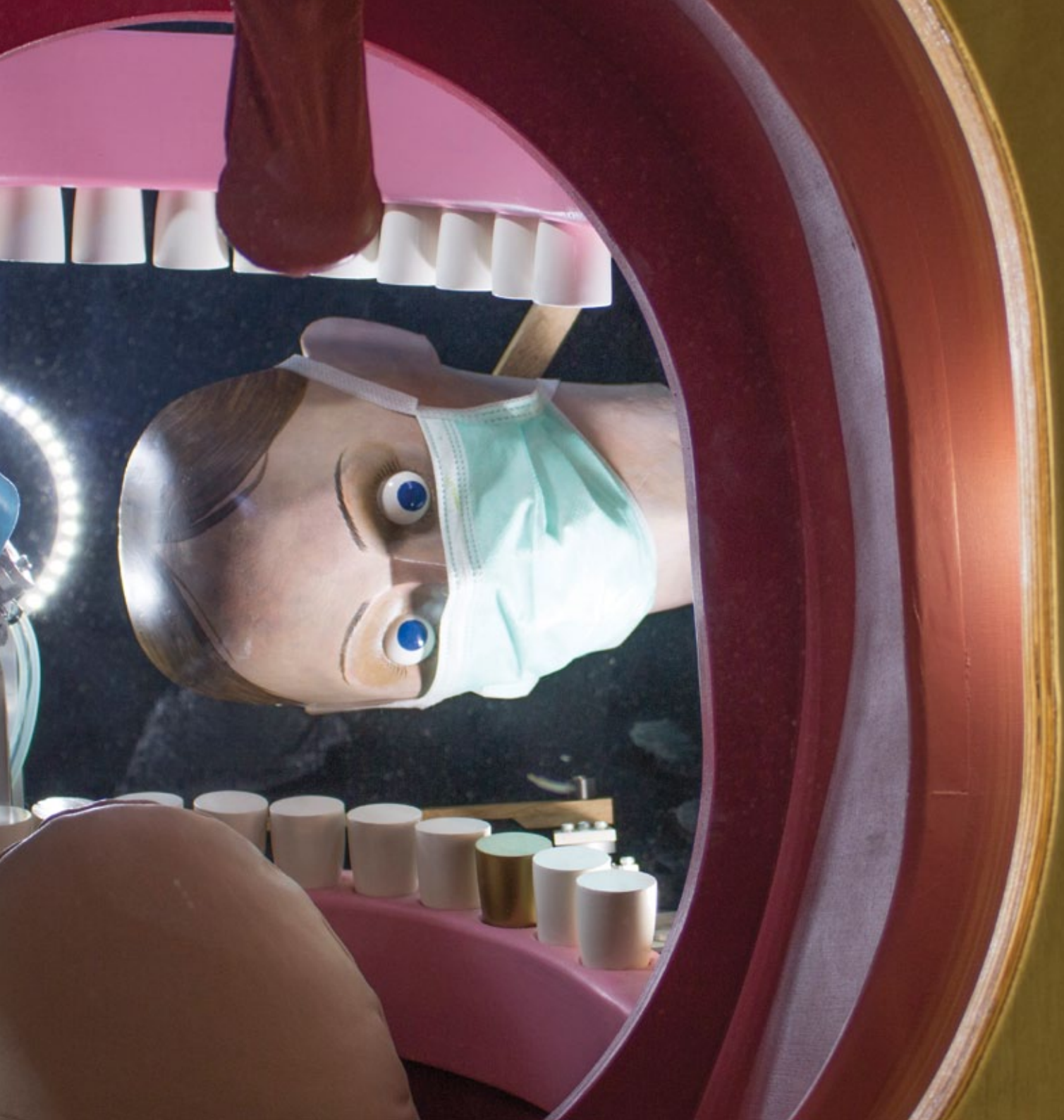
This mechanical model is meant to show some of the rudiments of an ineffably exquisite system using only those resources available to the average handyperson.

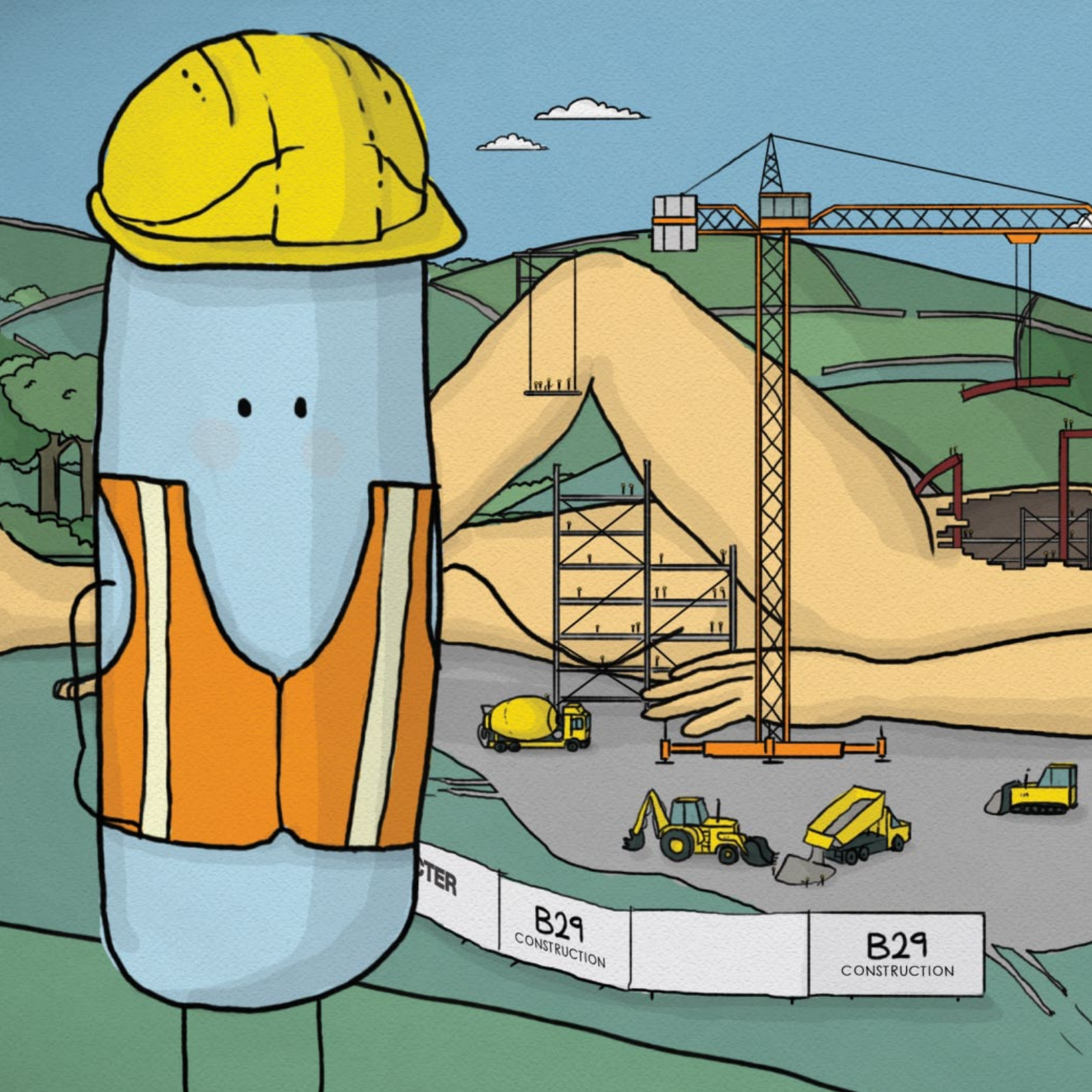
Playful and irreverent, yet educational, this installation uses mechanical movement to replicate the motions of our insides.

Paul Spooner is an artist and automata maker who combines humour with delightful and intriguing mechanisms. From tiny curios to magnificent contraptions, his work fuses storytelling, poetry, engineering and craftsmanship.

This project was developed in partnership with engineer Sam Lanyon from Concept Shed.







CTER

B29
CONSTRUCTION

B29
CONSTRUCTION

BELLYVISION APPARATUS AND THE LIKE

Owl'n'wolf

Animation

The microbial world that exists in (and on) our bodies is a microcosm of the human world.

It contains a diversity of complex communities and systems. It is a functioning society that, like ours, is constantly changing and evolving; wars are fought, alliances made, resources used and environments (us) are altered.

So how would this society document these events? In our world we use television, the mirror that records and repackages all of our events, desires, fears and prejudices as colourful entertainment. This piece imagines what a microbial television network (Bellyvision) might look like. Using the visual language and conventions of TV shows it explores a selection of stories from across our body's microbial community. In shows like 'MicrobeChef' and 'Grand Insides', we discover what influence microbes have on our food and nutrition; whilst 'Later with Lacto' and 'The Longum Arm of the Law' explore the links between microbes and our immune system.

Joe Holman is a multimedia artist and designer with a focus on visual storytelling and interpretation. His work explores the crossovers between digital and traditional techniques, using print, motion graphics and 2D/3D design.

www.owlnwolf.com



*‘If we didn’t have
bacteria in our gut,
it’s doubtful that the
human race would have
evolved to the extent
that they have.’*

Professor Simon Carding, Institute of Food Research and School of Medicine, University of East Anglia.
From *A Natural History of Me!*, Radio 4, 2012.

FORM US

News and Views from the Science Advisory Group – Dr. Maria Gloria Dominguez-Bello

April 17, 2015 – A multicenter team of U.S. and Venezuelan scientists, led by researchers from NYU Langone Medical Center, have discovered the most diverse collection of bodily bacteria yet in humans among an isolated tribe of Yanomami Indians in the remote Amazonian jungles of southern Venezuela. By comparison, the microbiome of people living in industrialized countries is about 40 percent less diverse, the scientists estimate.

“We found unprecedented diversity in faecal, skin, and oral samples collected from the Yanomami villagers,” says Maria Dominguez-Bello, PhD, associate professor of medicine at NYU Langone Medical Center and the senior author of the study. Among the Yanomami skin samples for example, the researchers found no single dominant taxonomic group of bacteria, in contrast to the U.S. skin samples, which showed lower diversity and relative high proportions of *Staphylococcus*, *Corynebacterium*, *Neisseriaceae*, and *Propionibacterium*.

The Yanomami villagers of this study, who have subsisted by hunting and gathering for hundreds of generations, are believed to have lived in total seclusion from the outside world until 2009 when they were first contacted by a medical expedition. Among a rare population of people unexposed to modern antibiotics, the villagers offer a unique window onto the human microbiome.

Investigating microbiomes unexposed to processed diets and antibiotics, Maria believes can shed light on how the human microbiome may be changing in response to modern culture, and therefore help point to new therapeutics that can rehabilitate disease-causing imbalances in the human microbiome.

Dr. Maria Gloria Dominguez-Bello is an Associate Professor at New York University School of Medicine. Maria’s research has often focused on microbiome differences between those living in North and South America. Her work has afforded fascinating insights into the differences that occur during pregnancy and the fact that those born by C-section tend to be characterized more by skin bacteria than those born by passing through the birth canal, who are predominantly colonized by gut microbiota from their mothers. This has important ramifications in some South American countries where the rates for elective caesareans in private hospitals can be as high as 80%.

FEED US

News and Views from the Science Advisory Group – Professor Michael Wilson

The main function of our human gut is to take in food – usually bits of animals and plants at one end, extract from these the things needed for our survival and growth (nutrients, vitamins and energy) and then dump what's left out of the other end. In the upper regions (mouth, stomach and small intestine) we produce enzymes that break down the large molecules ('macromolecules') such as proteins, carbohydrates and fats in our diet to small molecules that are then absorbed into the bloodstream. Why then do we have yet another 1.5 metres of gut (the large intestine or colon) tacked on? This is where most gut microbes hang out and this microbial community is often called the 'forgotten organ'. Why do we have this? To answer this question, we need to consider the enormous variety of foods humans consume – 2,000 different plants, 150 types of meat and 40 types of insects! Each of these contains many different macromolecules and their digestion requires a huge variety of enzymes. But studies of the human genome have shown that we produce only a limited number of digestive enzymes. In the case of carbohydrates, for example, we produce fewer than 20 different carbohydrate-degrading enzymes. However, the microbes in our colon collectively produce approximately 10,000 such enzymes. This is of great significance and demonstrates the remarkable benefits of a symbiosis. It means that, by providing a suitable environment in our colon for these microbes, we ourselves don't need to produce a vast range of carbohydrate-degrading enzymes and so we can leave carbohydrate digestion to our microbial partners. Colonic microbes use carbohydrates as a

nutrient source and in doing so produce butyric acid. This compound is absorbed into the bloodstream and performs a number of important functions. Not only is it a significant energy source (providing around 10% of our energy needs) but it helps protect against cardiovascular diseases, inflammatory bowel diseases, type 2 diabetes and colorectal cancer. Colonic microbes also produce several vitamins and essential amino acids and break down carcinogens in our diet. Finally, they regulate body fat storage and can help control obesity. Studies have shown that the ratio of two important groups of microbes in the colon (Firmicutes and Bacteroidetes) correlates with obesity – a high ratio of Firmicutes to Bacteroidetes pre-disposes to obesity. Interestingly, our diet has a dramatic effect on this ratio - a diet high in fibre decreases the ratio of Firmicutes to Bacteroidetes. Because our colonic microbiota has so many important functions, it's important that we not only learn more about this community but also find out ways of maintaining its composition in a way that ensures our health and wellbeing.

Professor Michael Wilson, Department of Microbial Diseases, UCL Eastman Dental Institute, University College London.

PROTECT US

News and Views from the Science Advisory Group – Professor Michael Wilson

The fact that complex organisms such as humans can survive on this lump of rock hurtling through the cold, empty vastness of space is nothing short of miraculous. Our survival on planet Earth is now recognised as being due, in part, to our indigenous microbiota. Consider for a moment that several million different microbial species live on our planet yet fewer than 2,000 of these have been detected on humans. Why? While many microbial species are not able to tolerate the habitats that a human has to offer, many others can survive in one or other of these habitats but are prevented from doing so by our microbial partners. This ability to exclude other microbes (including dangerous pathogens) is an important function of our microbiota.

The essential protective, developmental and nutritional functions of our microbiota are increasingly being recognised. The need to cherish our microbial partners and ensure that these communities are not disrupted is becoming ever more apparent. It is remarkable just how stable these communities are, in the absence of major changes in their environment. However, just as chemical warfare can have catastrophic consequences for human populations, toxic chemicals can wreak havoc in microbial communities. While antibiotics are of enormous benefit in treating infections, they can also cause major problems. One unwanted side-effect is the development of antibiotic resistance while another is the disruption of our indigenous microbiota. In a recent Europe-wide study, my own research has helped show that some, but not all,

antibiotics can cause long-term changes in the oral and gut microbiotas (www.ucl.ac.uk/antiresdev). Amoxicillin had little effect on the microbiotas whereas clindamycin decreased the proportions of many groups of gut bacteria for up to 4 months after treatment. Not surprisingly, such changes can interfere with the beneficial functions that these communities carry out, particularly their protective role. It is well known, for example, that antibiotics such as clindamycin can disrupt the gut microbiota to enable the proliferation of *Clostridium difficile* resulting in the life-threatening condition known as pseudomembranous enterocolitis. Such a possibility should make us be cautious and limit the use of these powerful chemicals to situations where they are appropriate.

Professor Michael Wilson, Department of Microbial Diseases, UCL Eastman Dental Institute, University College London.

The good, the bad and the ugly

Not all microbes are good all of the time. When they are 'bad' (i.e. cause disease) they are known as 'pathogens'.

Some cause disease if we come into contact with them (e.g. TB, cholera). Some are opportunists, OK most of the time, but occasionally turning nasty. *Staphylococcus aureus* lives in around 33% of people's noses without any problems. If conditions change (e.g. weakened immune system, change of diet, circumstance), *S.aureus* can become pathogenic and really get up our nose (causing boils, sinusitis, food poisoning, etc).

Some beneficial microbes turn bad if they get in the wrong place, such as crossing the gut wall into the actual tissues of the body. Or coming out of our noses during a sneeze to infect our skin. Most of our microbial companions are able to display a good side and a bad side (like Jekyll and Hyde) depending on the circumstances.

Others give and take. For example, one that has caused a localised inflammation may also help fire up our natural immune-suppressant system, assisting us to react better to allergens.

Tactical moves from the superbugs

Gangs

Microbes can get together as communities to form slimy biofilms with new ideas, chemicals, glues and protection mechanisms. Unwanted microbes in biofilms are trickier to shift.

Resistance movement

If it were not for antibiotics around a third of the people reading this might not exist so antibiotics do have a very important role. However bacteria evolve far faster than us (some can reproduce around every 20 minutes). Some have become antibiotic-resistant e.g. MRSA (Methicillin-resistant *Staphylococcus aureus*) which can cause mild to serious infections.

Waiting patiently

Many gut microbes die when excreted from their warm, air-free home. However one, *Clostridium difficile* (*C-Diff*), goes into stasis in the form of spores until it finds another body to infect.

Defender wipeout

When our protective microbes are disrupted, our susceptibility to infections can go up. Some antibiotics can wipe out defending populations of microbes. This could, for example, give *C.diff* the upper hand. In its mildest form *C.diff* can result in a dose of diarrhoea. In its aggressive form it can be fatal.

Microbial discoveries



1676—1683

Antonie van Leeuwenhoek discovers ‘animalcules’ then observes first evidence of them actually living on humans – in the mouth.



1847

Ignaz Semmelweis discovers that if doctors wash their hands in hospitals, the incidence of infectious diseases falls.



1857

Germ Theory of Disease. Louis Pasteur discovers the role of microbes in disease and fermentation and invents the process of sterilization.



1867

Joseph Lister develops antiseptic surgical methods.



1876

Robert Koch’s experimental methods identify microbes as the cause of disease.



1892

Dmitri Ivanovsky discovers the first virus – the tobacco mosaic virus.

The microbe arms race continues. Biomedical scientists fight back.

Could cures be more specific and targeted, involve new classes of antibiotics or help restore a healthy microbiome to do the fighting for you?

Tactical biomedical plans coming up the pipeline include:

New frontiers

New methods are enabling researchers to grow newly discovered bacteria. Welcome to *Eleftheria terrae*, which produces an antibiotic effective against many bacterial species. Even some superbugs can't resist it.

Probiotics (beneficial microbes)

Introducing a specific culture of microbes into diabetic mice led them to produce insulin. Could a probiotic someday replace insulin shots for people with diabetes?

Smart bombs

This treatment specifically attacks the unwanted bacteria by getting them to turn their own immune system on themselves (yes, microbes have immune systems too).

Ninja polymers

These non-antibiotic nanostructures target and kill specific bad bacteria then degrade themselves.

Strategic rumours

One bacterial strategy is to put out misinformation to confuse its competitors; just like humans did in wartime. Microbes converse with each other in a range of chemical languages ('quorum sensing'). How about targeting a specific bug with a specific message ('buzz off, this place is not for you')?

Bi-Fi

Bioengineers are exploring biological mechanisms to send genetic messages from cell to cell, nicknamed the biological Internet, or 'Bi-Fi'. Real targeting opportunities here.

Bacteriophages

Phage therapy using 'bacteriophages' (specific viruses that attack specific bacteria) has been around for years but was usurped by antibiotics after WW2 (unsurprisingly with battle wounds and infection to contend with). Time for a phage renaissance?



1909

Paul Ehrlich's research on developing a 'magic bullet' that would kill bacteria but not harm humans results in the development of a drug to treat syphilis.



1915—1917

Phage therapy, the use of beneficial viruses to treat bacterial infections, is discovered in England and in France.



1920s

Phage therapy is developed for use in the treatment of dysentery and other diseases, in the former Soviet Union.



1928

Alexander Fleming discovers penicillin from the fungus *Penicillium notatum*, the first effective antibiotic (i.e. a medicine produced by one microorganism that inhibits the growth of, or destroys, other microorganisms).



1940s

Large-scale production of penicillin makes it available to the general public.

Challenges of the 21st century

Health is not just about getting rid of the ‘bad guys’. The situation is far more complex. In the Western world infectious diseases are declining and non-infectious diseases are rising: eczema, asthma, forms of diabetes, heart disease, inflammatory bowel disease ...

Scientists are finding more and more associations between our microbiomes and our immune and nervous systems. Recent research shows potential links between a disrupted microbiome and some auto-immune diseases (which arise when our immune systems regard our body as the enemy and attack). There may also be links between our microbiome and other disorders such as clinical depression and obesity.

The ‘old-friends’ hypothesis’ suggests that under-exposure to microbes at an early age can result in a dysfunctional immune system that can then trigger auto-immune diseases later in life. Other theories suggest a link with overuse of antibiotics. If things go wrong when our microbiome is out of balance, could a re-balance help protect us from the diseases and disorders of the 21st century?

A cautionary note:

‘The microbiome has 400 million different variables that you can measure about it: the different sites, the different species, the relative abundance of those species, the variation—if you have that many variables, I can guarantee statistically that some of them will be perfectly correlated with Crohn’s disease and have nothing to do with it.’

Dr. Jonathan Eisen, professor and biologist in Microbial Ecology at the University of California-Davis.



1950s—1960s

The golden age of antibiotics. Many new antibiotics are discovered and mass produced.



1990s

Resurgence of interest in phage therapy as an alternative to antibiotics in the west.



1995

The first bacterial genome is sequenced (*Haemophilus influenzae*).



2003

Human genome sequenced.



2014

The World Health Organisation states that the rise of antimicrobial resistance (when bacteria change so antibiotics no longer work against them) is now the major threat to public health, in every region of the world.



2014

New antibiotic, teixobactin, discovered from soil microbe. Effective on some antibiotic-resistant strains of bacteria.

‘I am afraid that the experiments you quote, M. Pasteur, will turn against you. The world into which you wish to take us is really too fantastic.’*

La Presse, Paris, 1860.

*Louis Pasteur, (1822 –1895). Pasteur’s discovery that bacteria caused disease led to vaccinations, microbial fermentations and pasteurization.

ANTIMICROBIAL RESISTANCE IN THE ENVIRONMENT

News and Views from the Science Advisory Group – Dr. William Gaze

Whilst the majority of bacteria are harmless and often beneficial, a small proportion can cause disease in humans. The drugs we use to treat bacterial infections are known as antibiotics, first discovered by Alexander Fleming in 1928. Since then, a number of different antibiotics have been developed, but bacteria are fighting back, developing resistance to nearly all of our current drugs.

Antibiotic resistance poses a major threat to our health. The prospect of a 'post-antibiotic era' where people are more likely to become ill and even die from untreatable infections was recently highlighted by Dame Sally Davies, the Chief Medical Officer for England. In order that both current and new antibiotics can be used for as long as possible, we need to understand how antibiotic resistance evolves and spreads between bacteria and how these bacteria spread within the human population.

My research, at the University of Exeter campuses in Truro and Penryn, studies the evolution and spread of antibiotic resistance in the environment. This work has recently shown that coastal water users in England and Wales, such as surfers and swimmers, are at risk of exposure to bacteria resistant to antibiotics. My team, with our collaborators at the University of Warwick, have also shown that the majority of these bacteria are likely to come from waste water which is discharged into rivers and coastal waters, with some also coming straight from agricultural land.

But swallowing these bacteria doesn't necessarily make people sick, so the researchers are currently studying whether people who are highly exposed to resistant bacteria in recreational coastal waters, such as surfers, carry higher numbers of resistant microbes (both good and bad) in their gut. It is worth noting that resistant bacteria can also spread through person to person contact, via the food chain and by international travel.

What makes bacteria develop resistance to antibiotics in the first place? Most of the drugs we take pass through us into the environment and we believe that antibiotics in sewage and animal waste could encourage bacteria to evolve into immune strains. To find out, we are analysing water samples from rivers and waste water treatment plants, then conducting evolution experiments in the laboratory, to see if bacteria develop resistance at the concentrations of antibiotics present in polluted environments.

By better understanding the processes that drive antibiotic resistance, the team are hopeful that our work will help to inform reduction of the amount of antibiotic residues and resistant bacteria in the environment – removing the evolutionary pressure for resistant strains to develop and reducing the spread of resistant bacteria.

Dr. William Gaze, Senior Lecturer in Microbial Ecology, European Centre for Environment and Human Health, University of Exeter Medical School.





DON'T TRY THIS AT HOME

Anna Dumitriu

Textiles stained and patterned with gut bacteria, anatomical glass, prepared faecal transplant, carved wooden box.

In March 2014, faecal transplants were approved by the National Institute for Health and Care Excellence, NICE, for the treatment of long-term infections caused by the superbug *Clostridium difficile*.

This installation explores the complex story of these transplants. They have a high success rate in extreme cases where traditional antibiotic treatments have failed. It is not entirely clear how these transplants work and long-term effects are unknown. Faecal transplants performed in hospitals are carefully screened for harmful agents. It is a definite: 'don't try this at home'.

The intriguing work was developed in the laboratory in Leeds: pieces of calico have been stained and patterned with gut bacteria, a prepared faecal transplant sits in anatomical glass within a wooden box embellished with carved *C.diff* spores.

Anna Dumitriu is an artist working at forefront of art and science collaborative practice. Her installations, interventions and performances use a range of biological, digital and traditional media, in particular bacteria.

www.normalflora.co.uk

The project was developed in partnership with Dr. Caroline Chilton & Dr. Jane Freeman at the Healthcare Associated Infection Research Group at University of Leeds and Leeds Teaching Hospitals Trust.

PHAGES

Aimee Lax

Porcelain, acrylic glass

Bacteriophages are tiny viruses that only attack specific bacterial cells. Phage therapy has been used in the past. Today they are once again being researched and engineered as an alternative to antibiotics.

This sculptural installation is a celebration of these extraordinary creatures. Imperceptible to the human eye, these delicate but tough organisms are extremely abundant and resemble a cross between a spacecraft and an insect. They are incredibly unusual yet somehow familiar. Sometimes the truth really is stranger than fiction!

Close to a hundred individual bacteriophages, handmade in porcelain clay, are represented attacking an acrylic glass bacterial cell. They do this by injecting their nucleic acid (DNA or RNA) into the cell, where the viruses use the bacteria's DNA and resources to replicate themselves. They then burst through the cell wall, destroying the cell in the process. Scientists are looking into how these creatures could be used as a new form of antibiotics, where they target only the 'bad' bacteria, preserving the 'good' ones.

Aimee Lax's work explores our relationship to nature. She explores themes of attraction/repulsion, familiar/unfamiliar and the idea of 'other-worldliness' – how some species on our planet seem just too strange to be real.

www.aimeelax.co.uk





Health & well-being

Thanks to advances in medical science many of us are leading longer, healthier lives. Currently our microbiome is under the lens.

The food we eat and chew, the exercise we do, the medicines we take and the hands we often shake can all affect our microbiome – either temporarily or more long-term. So does who we are, where we live, our sex, jetlag, our environment and our situation. It's dynamic and complex.

We are 99% genetically identical to each other in our human cells but radically different in the genetic content of our microbiomes – different microbial communities performing the same functions in different people and different places. It's all about balance.

In terms of health there are commonalities and common sense to be had. You may wish to:

- Nurture your microbiome with a healthy, balanced diet
- Take supplements: probiotics, prebiotics and synbiotics (= pro + pre) and fermented foods. Some swear by them, some swear about them.
- Stay calm, get enough sleep, keep stress low
- Take exercise, get outside and interact with your environment. It's teeming with microbes and most of them are good for you.
- Wash your hands (the pathogens tend to be hitch-hikers and therefore easier to remove) and chew your food (so your stomach can kill off the pathogens and ... it helps reduce indigestion)

And as for the future?

Day by day new scientific discoveries are enabling us to review and realise new complexities in our microbial world and our relationship with it: what is there and what it does.

In the future, will we:

- Have our microbial profile in our medical records?
- Be able to adjust our microbiome for good health?
- Develop pre/pro-biotic medicines/optimal buildings?
- Re-connect more with the great outdoors?
- Have targeted medicines and personalised therapies?
- Better understand allergies and auto-immunity?
- Use fewer or more targeted antibiotics?
- Use microbes to fight disease?

And even:

- Develop bacterial skin creams and attractant perfumes?
- Eat live yoghurts or other fermented foods that treat obesity, diabetes, anxiety?
- Drink microbial supplements to boost mood and intelligence?

Or are some of these things already happening?

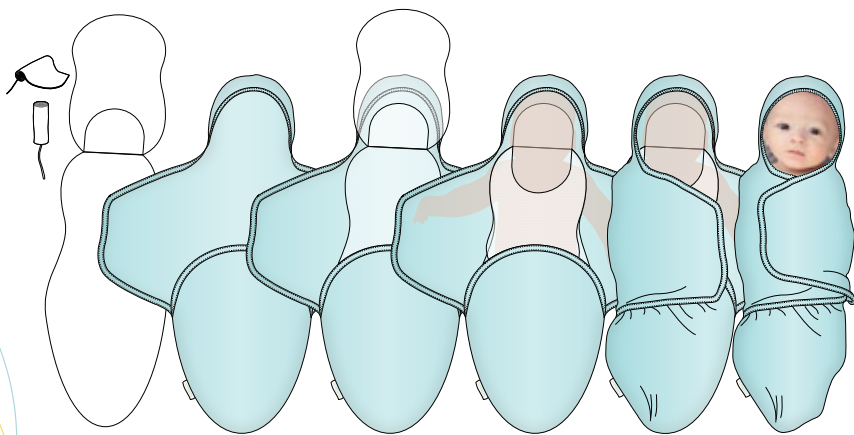
Daily new scientific techniques are enabling us to view and study and realise the complexity of our microbial world.

Will our belief systems be challenged yet again? If we are a community and many of our microbial inhabitants can reproduce every twenty minutes – are we now capable of evolving within our own lifetimes?

A cautionary note:

'We are discovering a whole new ecosystem. But I do have some fear—we all do in the field—that the hype and the potential overpromise, and the idea that somehow this is going to be different—there is a terrific fear that it will all backfire.'

Dr. Lita Proctor, head of the National Institutes of Health Human Microbiome Project, an outgrowth of the Human Genome Project.



Babybiome by Katy Green



Inner Garden by James Washington

RSA STUDENT DESIGN AWARDS

Joint winners: Katy Green and James Washington

Working with the RSA (Royal Society of Arts), we asked students from around the world to design a means of encouraging people to take care of their human microbiome.

Babybiome by Katy Green is a product and a campaign that helps people understand the importance of nurturing a healthy microbiome from birth. Based on existing scientific research it includes a 'seeding' blanket to help develop the baby's microbiome after caesarean section births and an information campaign to promote natural birth.

Inner Garden by James Washington is an all-encompassing health brand that includes an app, a book and a healthy food range. It's a helpful everyday guide and informative campaign to help people find ways of taking care of their microbiome.

Hello. I'm Probiotics :0 by Liang Huang is a set of two interactive encyclopedias for children and parents, focussing on beneficial microbes.

GloGro by Robert Wylie & Timothy O'Sullivan is a product and design service where parents can track the development of their child's microbiome.

The RSA Student Design Awards are an annual competition and global curriculum that challenge students and recent graduates to think differently about design.

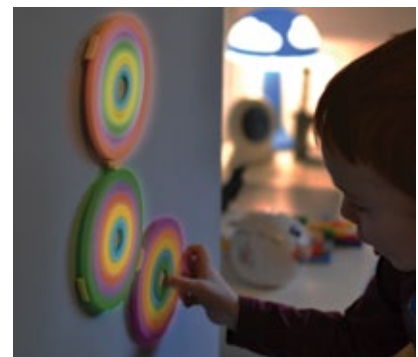
sda.thersa.org

Highly commended:

Hello. I'm Probiotics :0
Liang Huang



GloGro
Robert Wylie & Timothy O'Sullivan



‘We just happen to look human because our human cells are much larger than bacterial cells ... no matter how you look at it, it’s high time we acknowledge that part of being human is being microbial ...’

Dr. Julie Segre, chief & senior investigator, Human Microbiome Project,
National Human Genome Research Institute, Bethesda.

‘... some 90 percent of the protein-encoding cells in our body are microbes ... 99 percent of the functional genes in the body are microbial ... exchanging messages with genes inside human cells ... microbes co-habiting our body outnumber human cells by a factor of 10, making us actually “superorganisms” that use our own genetic repertoire as well as those of our microbial symbionts ...’

George Johnson, The New York Times.

Notions of self

What does it mean to be human?

We are not alone. We are a community, a living ecosystem made of many parts. Our microbes help form, feed and protect us and may partially determine our shape, health, mood, even our character.

Who's in charge? Our personal microbiome reflects our environment and our environment reflects our microbiome. We swap and share microbes with our partner, family, close friends and our pets.

So are you really who you think you are?

A question of scale and the recipe of you

10 trillion human cells in each of us

100 trillion microbial cells in each of us

20,000 human genes

2–20 million microbial genes

Each of us plays host to 10 x as many microbial cells,
100 x as much microbial DNA as our own.

MICROBIAL ME

Mellissa Fisher

Agar, bacteria, video

In the knowledge that our bodies contain more bacterial cells than our own, what does it mean to be human? Are we just platforms for other living organisms? What is our 'self'?

Using the traditional form of a self-portrait, this living artwork is made from a cast of the artist's face using agar and swabs from her skin. The bacteria from her face grow and mix with the colonies of microbes present in the environment. It flourishes, matures and dies, reflecting the cycle of life and exploring the relationship between us and our microbiota. Treading the fine line between curiosity and disgust, this sculpture invites the viewer to question how they define themselves and their perception of microbes.

Mellissa Fisher trained as an illustrator and is studying for a Masters in Art and Science at Central Saint Martins. She is particularly interested in the interdisciplinary practice and public engagement in science.

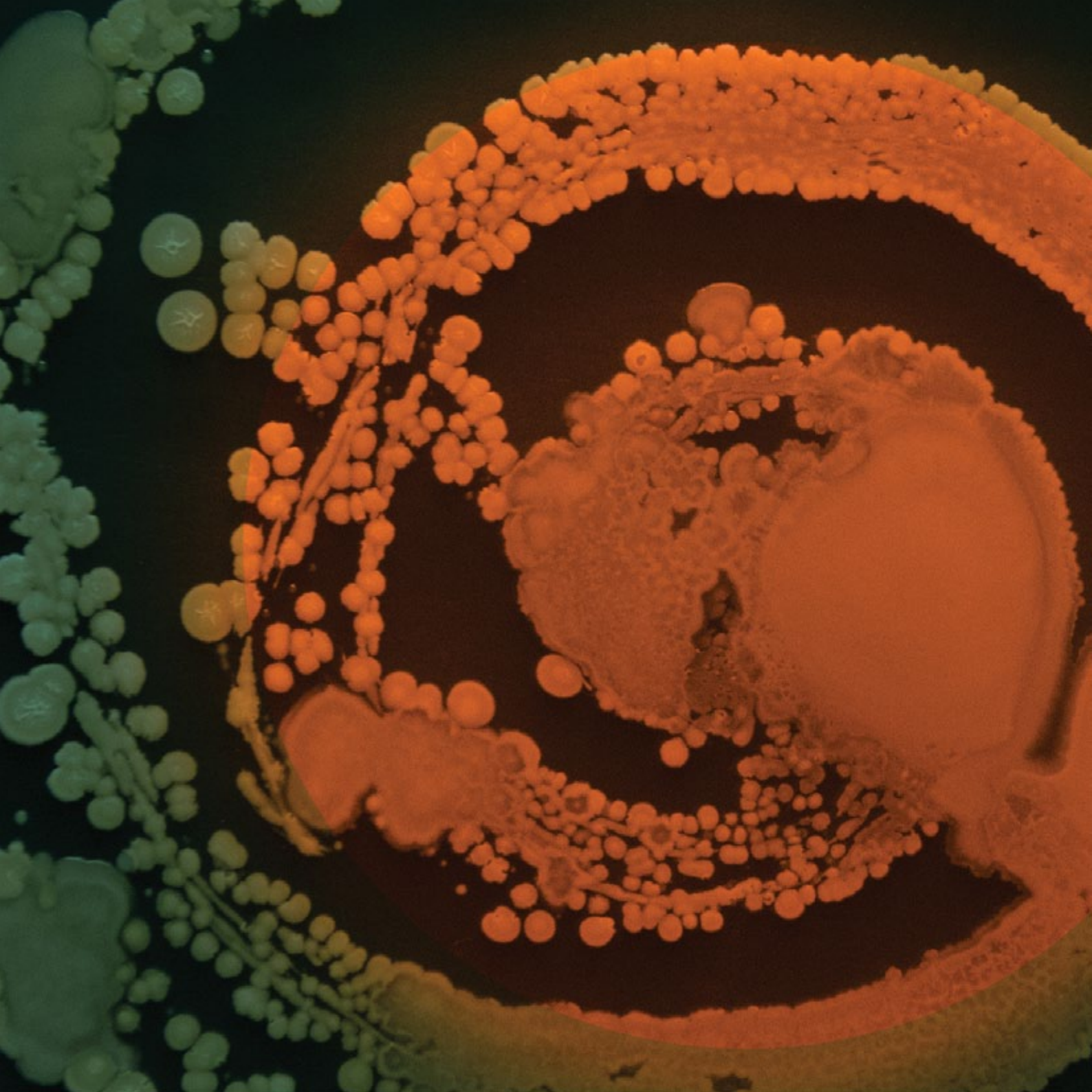
www.mellissafisher.com

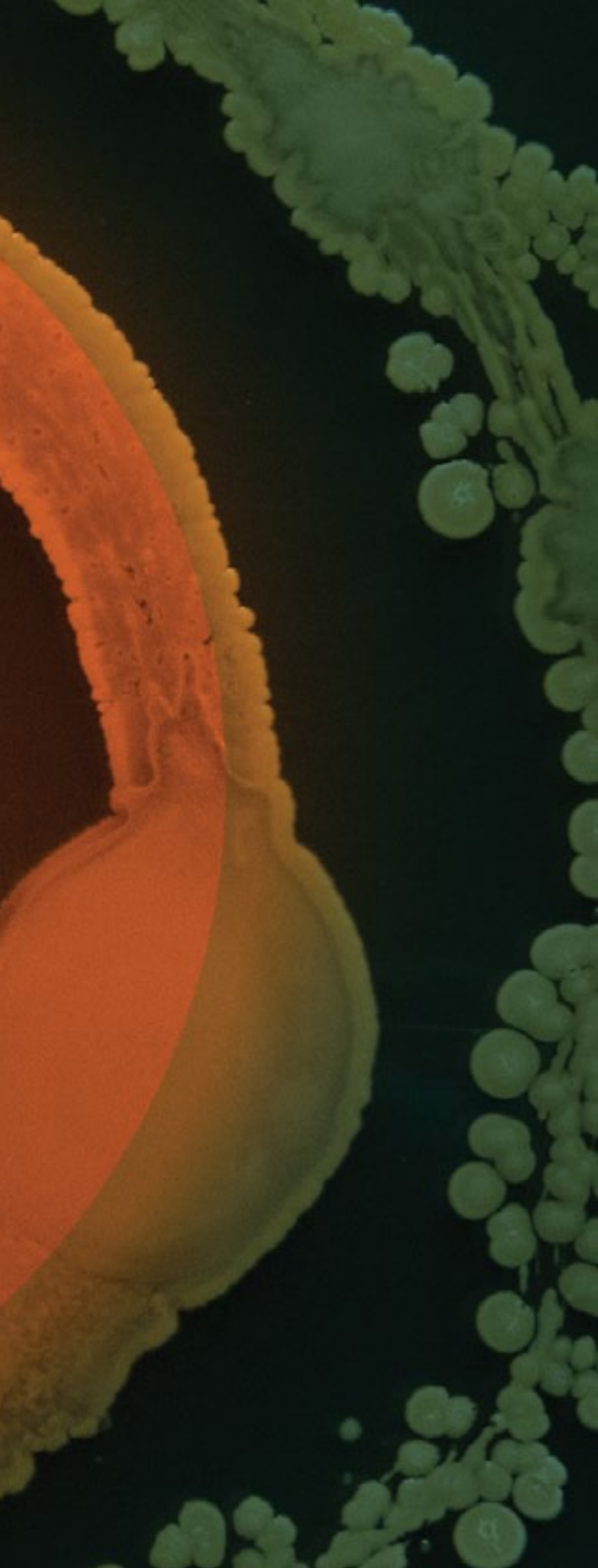
This project was developed in partnership with Dr. Mark Clements, University of Westminster, and Dr. Richard Harvey, Kings College London.

Supported by Thermo Fisher Scientific.









OTHER SELF PORTRAITS

Joana Ricou

C-print of bacterial painting

We are made of many parts and many types of parts.

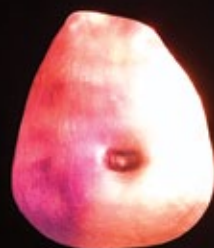
These portraits were created using the microbiome of the subject as a painting medium. Each portrait is a culture of the bacteria and other living things collected from the subject's bellybutton. It is thought that the microbiome of each person is as unique as our fingerprint, and that it comes from our environment and from our mothers.

This series questions our perceptions of ourselves and explores how the microbiome blurs our fundamental boundaries: between human and non, organism and environment, between generations, and between all of us. To see more portraits online, visit microbialart.tumblr.com

Joana Ricou uses biology as a starting point to explore the boundaries and discontinuities of the human body. The resulting works include traditional art media like oil painting and laboratory media like Petri dishes and bacteria.

www.joanaricou.com

This project was developed in partnership with Dr. Rob Dunn and Holly Menninger of North Carolina State University and with Dr. Julie Urban of the North Carolina Museum of Natural Sciences.



ANTHROPOCENE

Vicki Shennan

Film and sound installation

From the microscopic to the macroscopic, are thousands of systems, sequences and patterns hidden in Nature. How do we make this complex invisible world visible?

The body itself is an ecosystem, teeming with microorganisms. We are gradually becoming aware of how crucial microbes are for human health and the need to protect these diverse habitats.

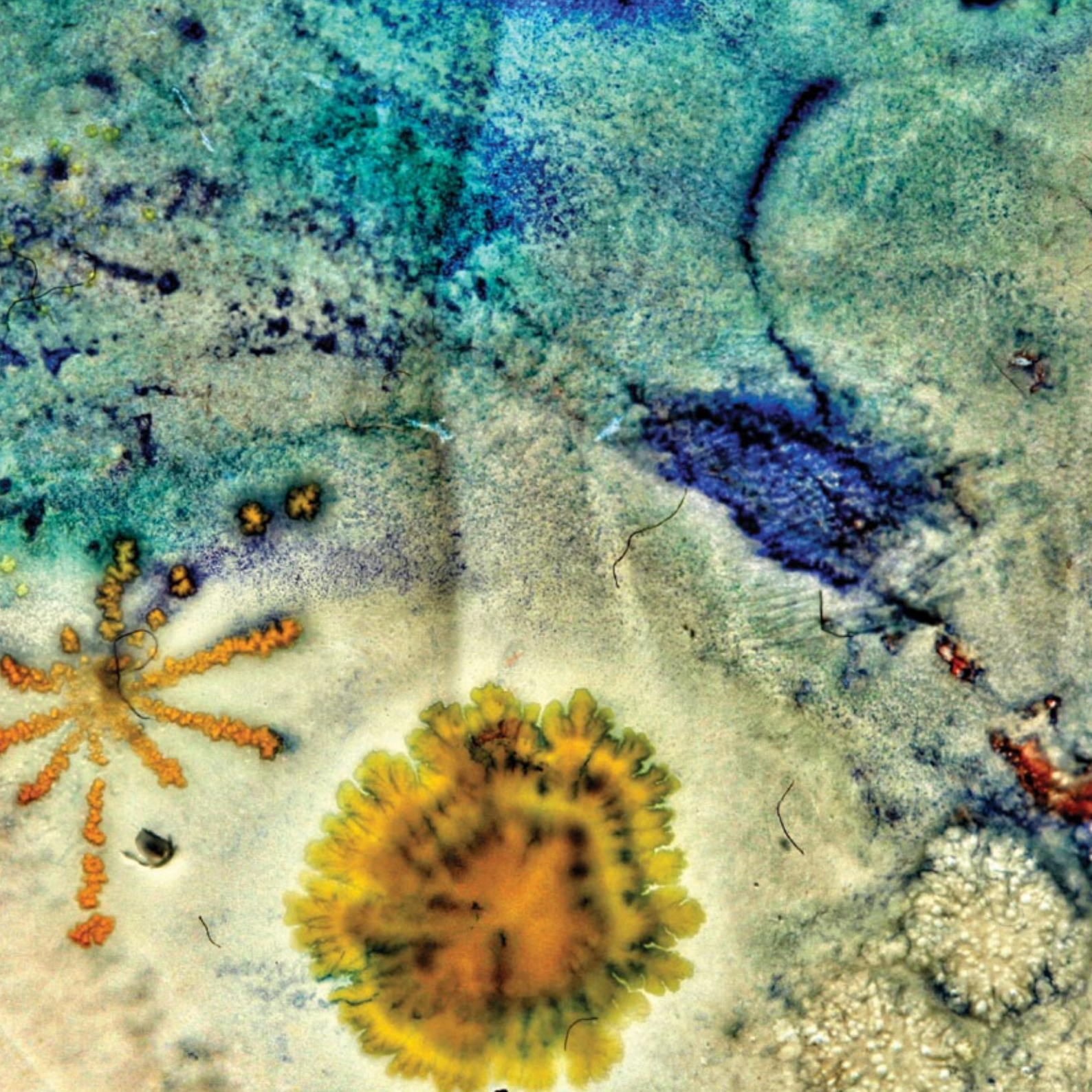
To reveal and capture the symbiotic relationship humans have with their microbes, the team has translated the RNA* sequences of microbes and the 3D structure of crucial proteins they produce into sound compositions. Using data of 3 areas (the hand, mouth and gut), this musical piece and projection turns an invisible world into a sensory symphony. It explores life at a micro scale, illustrating the rhythms of nature that underpin our existence.

*Ribonucleic acid molecules – used in protein synthesis and for the study of gene expression in genetics.

Victoria Shennan, MA Royal College of Art, is an interdisciplinary artist who explores the human condition and the transient, unseen world that surrounds us.

www.cargocollective.com/victoriashennan

This project was developed in collaboration with composer Jack Hurst from the Royal College of Music and Dr. Linda Long, the award-winning creator of Molecular Music from the University of Exeter Medical School.



THE MAN WITH THE MICROSCOPE

News and Views from the Science Advisory Group – Dr. Simon Park

‘That as men busied themselves about their various concerns, they were scrutinised and studied, perhaps almost as narrowly as a man with a microscope might scrutinise the transient creatures that swarm and multiply in a drop of water.’ From H. G. Wells, *A War of the Worlds*.

I read “The War Of the Worlds” by H. G. Wells as a young teenager, and its opening lines were my first, and career defining, introduction to the wonder and hidden power of microbiology. I realised then that all life on Earth was dominated by invisible organisms that I couldn’t see, and knew then that I had to become a microbiologist. Returning again to science fiction, and as a thought experiment to demonstrate the unseen importance of bacteria, I often imagine a scenario where we invent an incredibly powerful antibiotic that rapidly kills off all of the Earth’s bacteria and what would happen if this was released. It’s believed that if this happened, complete societal collapse would occur in just a year, as a consequence of the rapid and catastrophic failure of the food supply chain. Ruminant livestock would starve within days, and without bacterial nitrogen fixation, all plants would begin to die within a matter of weeks.

I combine art and science in my outreach activities, either through collaborations with artists, or through my own practice, because of the powerful way it can catch people “off guard” and draw them into a world that they would otherwise rarely consider, in ways that the formal scientific process can’t. For example, I can still remember the initial shock, and then the slowly emerging amazement in people when they learnt that

a beautiful painting that we had made of John Millais’s Ophelia, was in fact made entirely from living and naturally pigmented bacteria.

The image opposite stems from my thought that for every artist, either living today, or dead, that the body’s microbiome, that is its invisible hundreds of trillions of bacterial cells, would have made at least some contribution to the artist’s work, in terms of influencing the mood or health of the artist. Here, I gave this usually invisible aspect of ourselves the opportunity to paint for itself, away from my conscious intervention. Colourless bacteria from my own microbiome were mixed with traditional watercolours (red, blue and green) and left in a warm incubator to interact with these overnight. The following morning I discovered that the bacteria had picked up the paints, and then moved these watercolours around the medium, in the same way that an artist might paint. The paintings are thus unique self-portraits, being direct manifestation of the power, activity and complexity of my other bacterial self. These microbiomal paintings were produced by the bacteria from my hand, gut and mouth.

Dr. Simon Park is a senior teaching fellow in the Faculty of Health and Medical Sciences at the University of Surrey. He documents his many art and microbiology projects at www.exploringtheinvisible.com and recently won the Peter Wildy Prize for his outstanding outreach work in microbiology.

Microbiome to Macrobiome

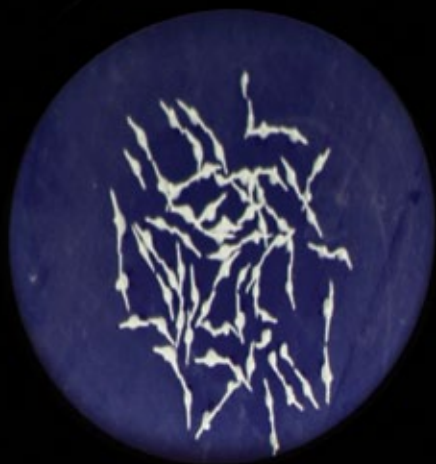
The Eden Project connects us with each other and the living world exploring how people can work together and with nature towards a better future.

Time to scale back up. The world around us is comparable to our individual microbiomes:

- The planet is a vast ecosystem with plants, animals and microbes interacting and working together in a giant web creating a living system and environment for us all to live in
- There are macro food webs, mergers, climax communities and interrelated biological systems on a massive scale
- Diversity is very important (on the macro and micro scale). Each species plays a role in the interconnected robust web of life. When diversity is lost, parts of the web break down. If key species are lost the web can collapse.
- The earth breathes, its temperature fluxes, it circulates water, nutrients and gases and has a series of feedback loops that keeps things in check

You are one of the 7 billion living in a giant macrobiome. How will you treat your host?





5e+16

Bill Wroath

Interactive film installation

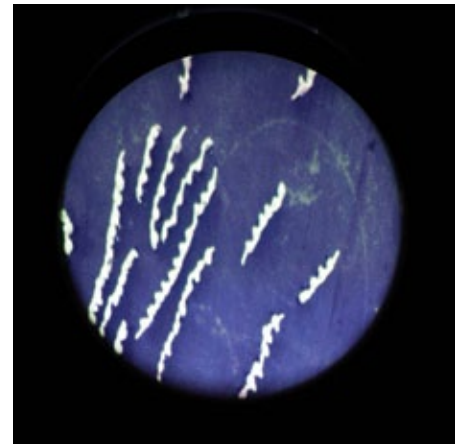
Bacteria communicate through a chemical language called quorum sensing. They co-operate and work together within the complex ecosystem of our bodies. Their networks and systems are comparable to our own systems and to our planetary systems.

To depict these internal mechanisms, Bill and choreographer Jules Laville translated how bacteria move and 'talk' into a choreographed dance. Inspired by the movements microbes make under the microscope and their collective nature, the team brought together hundreds of volunteers from across the local community to create a mass dance film. Up to five hundred people came together in a spirit of co-operation and community bringing with them their 5e+16 (fifty thousand trillion) bacteria. During the lifespan of the exhibition viewers will be invited to 'join' an online version of the dance and to reflect upon the interdependence between themselves, their microbes and the wider planet.

Bill Wroath is a multidisciplinary artist whose installation work encompasses ceramics, theatre, performance and film.

www.microbesonthemove.com

This project was developed in partnership with Jules Laville, Dr. Simon Lock, Gemma Ward, Laura Coutts, Sarah Farrow-Jones, Jane Spurr, Suzie West, Josie Wroath and Kizzy Wroath.



*‘The world is full
of magic things,
patiently waiting
for our senses to
grow sharper.’*

MICROBES: THE PLANET'S ULTIMATE CHEMISTS

News and Views from the Science Advisory Group – Dr. Jack A. Gilbert

Microbial ecology has undergone a renaissance recently as many fields of scientific enquiry have started to embrace the complexity of the microbial world. The microbial world comprises the bacteria, archaea, protists, fungi and viruses that dominate our planet. Ecology is the study of complexity. An ecosystem, such as a human gut, a lake or a forest soil, is a dynamic interaction between the biological, chemical and physical components of that world. Ecology aims to understand these components, and to describe and quantify how they interact.

Microbes are the best chemists on the planet, one of the most elegant examples of this is how they fix nitrogen from the atmosphere into their cells to build proteins, DNA, and all the molecules they need for life. We have figured out a way of doing this in the lab, but it is far from elegant. Compared to bacteria - the only life forms that can fix elemental nitrogen into organic matter – our technique is messy, energy-hungry and wasteful. Hence, understanding how microbial ecosystems function has a lot to teach us about how to live more sustainable lives.

My research is focused on understanding the building blocks of our microbial worlds. I do this because of a fundamental need to understand these systems, to unravel the complexity and make sense of these chemical engines. Microbes interact by passing chemicals between each other. In multicellular life, you would be familiar with these as pheromones. But bacteria, for example, have evolved potentially millions of ways of talking to each other. I am interested in deciphering their

dictionary, starting with the genome, that blueprint that tells me what a microbe can and cannot do.

Microbes are everywhere, so I can practice my research anywhere! My research group works in oceans and seas, lakes and rivers, forests and grasslands, plants and animals, and of course humans, to uncover the basic trends that define microbial communication across the planet. We also work in buildings and cities to try and find ways to build healthier environments for our children to grow up in; for example our studies are indicating ways that we could seed healthy mixes of microbes into our homes, public buildings and hospitals to stop dangerous colonies of bacteria and viruses from finding their way in.

We are also looking for ways to harness the microbial world around us to help clean up pollution, to provide biomarkers to tell us when the world goes wrong, to find ways to improve crop yields, and to cure diseases. In humans, we focus on allergies, asthma, autism and Parkinson's as these all have some basis in a breakdown in how bacteria communicate with our body. Similarly, we are developing ways of treating infections acquired in hospitals during surgery, by looking at a hospital building or surgical theatre from the perspective of the microbe, and finding ways to keep them happy so as to stop them from attacking us.

Dr. Jack A. Gilbert is principal scientific investigator for the Earth Microbiome Project, The Hospital Microbiome Project, Home Microbiome Project and a key collaborator in The Human Microbiome and The American Gut Projects.

'It's a fact of our lives we move through unseen legions: bacteria, viruses, protists, fungi, so we wash, we disinfect, we keep the inside out, but our individual insides, they aren't individual at all. What is human in our bodies is outnumbered by trillions of strangers.

You're like a wild island, a forgotten rainforest and so am I, and we're not just ambulant hotels, we're communities with gate keepers, janitors, nurses, farmers, builders, drones. Our newborn safety, our chemical balance, our ability to eat, it all relies on our tiny collaborators, their happy accommodation, their ability to reproduce in us.

So when I say it's a pleasure to meet you, I mean it's a pleasure for us to meet all of you, and to know that we are both as wonderful and crowded as we sometimes feel. How do you do?'

A. L. Kennedy, writer and performer.

Thank you

A huge thank you to all at the Wellcome Trust and particularly those involved with the Society Award without which this project would not have been possible.

Thanks to all the artists, the science advisory group, the project managers and their team, the Royal Society of Arts and all the students who entered the competition, Sir Tim Smit and Dr. Tony Kendle who, way back, came up with the beginning of the idea, (macrobiome to microbiome), and all at the Eden Project and our family, friends and colleagues who have heard about nothing except the stories of our microbiome for the past two years.

Dr. Jo Elworthy.

The Invisible You team, Eden Project:

Gabriella Gilkes, Science Project Manager.

Celine Holman, Art Project Manager.

Dr. Jo Elworthy, Director of Interpretation.

Artists:

Rogan Brown, Anna Dumitriu, Mellissa Fisher, Rebecca D. Harris, Joseph Holman, Aimee Lax, Alex May, Joana Ricou, Vicki Shennan, Paul Spooner and Bill Wroath.

Science Advisory Group:

Dr. Maria Gloria Dominguez-Bello, New York University.

Dr. William Gaze, University of Exeter Medical School.

Dr. Jack Gilbert, University of Chicago.

Dr. Rob Knight, University of California, San Diego.

Dr. Simon Park, University of Surrey.

Dr. Michiel Vos, University of Exeter Medical School.

Professor Michael Wilson, University College London.

Our collaborators:

Dr. Caroline Chilton and Dr Jane Freeman,
University of Leeds.

Dr. Mark Clements, University of Westminster.

Dr. Martha Clokie, University of Leicester.

Dr. Rob Dunn and Holly Menninger, North Carolina
State University.

Dr. Richard Harvey, King's College London.

Dr. Linda Long, University of Exeter Medical School.
Royal Society of Arts Student Design Awards team.

RSA Student Design Awards:

Winners - Katy Green and James Washington

Highly-commended - Liang Huang, Robert Wylie and
Timothy O'Sullivan.

Graphic Design: Paul Barrett, Eden Project.

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‘There’s still a lot to know ...’

Dr. Lita Proctor.



eden project

www.edenproject.com