FABER FUTURES
IN COLLABORATION WITH
WORLD ECONOMIC FORUM

BIO STORIES

Re-envisioning relationships with nature

REPORT
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PREFACE

by Dr. Megan J. Palmer

We are at a transformative moment in our relationship with nature, the living world and ourselves.

Developments in synthetic biology now enable reading, writing, editing and evolving the building blocks of living systems with increasing ease and precision. We can encode our intentions into life like never before.

But as we learn to engineer the living world, how do we ensure we are shaping a world in which we wish to live? How do we make sense of the significance these transformations hold for our lives, our societies, and our planet? How do we confront our human biology within these complex ecologies? How do we teach each other about our dreams for our biological future? How do we connect our past and our present to these potential futures? How do we constructively question the status quo to create space for something better that we might synthesise together: a more symbiotic world?

These questions led to the birth of BIO STORIES from what might seem an unusual place: the World Economic Forum. In 2020, amid a pandemic that forced us all to revisit our ways of life and our security, the Forum convened a Global Future Council, spanning disciplines, professions and geographies, to explore what might be at stake in the ways we advance synthetic biology.

The council was intentionally selected and somewhat subversively charged with questioning whether the values that underlie our current systems would serve our shared biological futures. We reflected on how to centre sustainability, solidarity, equity and humility in our pursuits. We questioned whether we might de-centre technology as the problem or the solution. In the face of calls by the World Economic Forum to pay attention to how biology factored into the 'Fourth Industrial Revolution', we asked how we might imagine biologising industry instead of industrialising biology. When a select few people were asked to craft a narrative about what comes after the Great Reset, we asked how we could inspire many people to enter into dialogue about envisioning and realising futures in ways that empower and embolden everyone.

The council quickly recognised that synthetic biology could open up new strategies to help us confront the many crises that became increasingly pronounced during the pandemic: from creating sustainable options to counter a changing climate to protecting against biological threats. However, the foundation for developing these strategies required first being able to imagine our shared futures. We needed *new stories.*

Why? The stories we tell ourselves shape our visions for the future and the strategies we use to bring them to life. The stories commonly

recited about our biological futures were boring at best, polarising at worst, and often alienating. Magazine covers foretold a future where biology would both save and destroy the world, seemingly simultaneously. Advertisements invited us to dream of a sustainable future, but buying in required buying more things. Market reports told stories of the massive profits of the biological revolution, but only for those who could afford to invest. Even our scientific stories were so often focused on the details of manipulating molecules that it was often hard to tell why it mattered. We were missing inspiring stories about what was at stake for everyone, told by everyone, that helped us all connect our past, present and potential biological futures. We needed stories that moved us. BIO STORIES sought to curate, connect and create a set of essential stories: the stories of our lives and our relationships within the living world.

What you will find in these pages is a living prototype of a process for intentionally creating collective stories about flourishing futures in partnership with living systems. The process of creating BIO STORIES has reminded me of the simple power of conversation to help us understand each other, so we can begin to dream together. When we take the time to listen carefully, profound understandings and beautiful possibilities can emerge. We are all biological beings. Creating a more beautiful biological future for everyone is possible if we can learn to dream together. I wish that BIO STORIES inspires you to connect, to think and to act in ways that transcend what is expected.

Dr. Megan J. Palmer is the Executive Director of the Bio Policy and Leadership Initiatives and Adjunct Professor in the Department of Bioengineering at Stanford University. She is currently co-chairing the World Economic Forum's Global Future Council on Synthetic Biology.

INTRODUCTION

In 2020, the World Economic Forum convened the Global Future Council on Synthetic Biology, aiming to articulate how synthetic biology could benefit people and the planet and to define the kinds of values that would enable effective, equitable and ethical outcomes in its deployment. The Council's work considers the narratives, assumptions and visions of a world changed by this technology, in order to ensure that this world does not replicate the inequities of the past. The council states that: 'If synthetic biology is to realise its full potential, it must have values at its core.'[1] If stories are a means to embody and advance values,[2,3] then how do we solicit new, value-driven narratives and place them in context to clarify what is at stake in the ways that synthetic biology is advanced?

BIO STORIES is an interdisciplinary project that draws together curation, design, anthropology and fiction to develop a method for mutualistic storytelling. With synthetic biology now firmly on the global agenda as a technology that can reshape our relationships with the living world, BIO STORIES contextualises it into narratives that reveal what we prioritise as being key to continued human development. These stories are powerful because they provide a theatre in which to imagine the kind of a world we wish for. They give us space to explore how we might distribute agency and power in order to enact the radical change required to meet the most pressing challenges of the 21st century: climate change, biodiversity loss and global inequity.

To create space for emergent narratives, BIO STORIES employs a curatorial strategy that crafts connections and establishes common ground between scientists, farmers, designers, investors, community leaders, artists, entrepreneurs and others. Through shared dialogue, they relate back to one another their perspectives and approaches to the living world. Existing power dynamics and entrenched framings often render synthetic biology elusive or impenetrable to stakeholders who nonetheless carry valuable knowledge and capabilities. The ambition to ensure what is at stake is visible and approachable is essential to BIO STORIES and achieved through accessible language, considered meetings of minds and inspiring springboard questions.

To create conditions conducive to unexpected insights and connections, BIO STORIES upends existing strategies for stakeholder engagement by foregrounding creative, design-led methodologies. BIO STORIES is a collection of tools, spaces and frameworks that actively empower[4]—not just expanding who sits at the table, but making it possible to share and engage across plural perspectives.[5] Each stakeholder provides an artefact as a conversational entry point. The artefact materialises complex lines of questioning and makes tangible various visual imaginaries that advance dialogue.

The dialogues demonstrate global and multidisciplinary accounts of what issues arise from the ways that synthetic biology interfaces with society. But, when regarded as a collective, they reveal something else: intertwined and plural visions of what it means to work, think and live with nature. To further animate and broaden access to these syncretic narratives, the conversations are translated into several distinct BIO STORIES: a speculative journey through a biological future and its analytical counterpart that reveals what this might mean for today. These stories are grounded in plural human practices from across the world via material artefacts and personal testimonies shared by the BIO STORIES participants. The process is then made transparent for others to continue the work and iterate its methodologies across multiple contexts. Finally, we offer reflections from across the Global Futures Council for Synthetic Biology on what the BIO STORIES point towards for the future of synthetic biology.

This report is not intended to be a static documentation, but rather a versatile toolkit that can inform future visioning and visionary work. There are multiple ways to use it:

- Read in order, journeying through evocative fiction to practical instructions for further iterations;
- Immerse yourself in the collection of artefacts before following the threads to reveal connections across the set;
- Discover our process, organise a dialogue and use these stories as a prompt.

We hope that by following the threads across BIO STORIES, you encounter many more entanglements, narratives and possible futures for the fundamental and exceptional technology that is synthetic biology.

Let our stories begin here.

1. World Economic Forum (2021) Revisiting and Realizing the Promises of Synthetic Biology. Briefing Paper. [online] Available at: https://www3.weforum.org/docs/WEF_Revisiting_and_Realizing_the_Promises_of_Synthetic_Biology_2021.pdf, p. 3.
2. Scott, W. J. (2011) 'Forum: Holberg Prize Symposium Doing Decentered History: 2. Storytelling', History and Theory, Issue 50, pp. 203-209. Available at: http://culturahistorica.org/wp-content/uploads/2020/02/scott-storytelling.pdf.
3. Episkenew, J. (2009) Taking Back Our Spirits: Indigenous literature, public policy, and healing. University of Manitoba Press, pp. 1-109.
4. Costanza-Chock, S. (2020) Design Justice: Community-led Practices to Build the Worlds We Need. Cambridge, Massachusetts: MIT Press.
5. Escobar, A. (2018) Design for the Pluriverse. Durham and London: Duke University Press.

GATHERING

BIO STORIES prototypes and offers conceptual, curatorial and symbolic tools that facilitate storytelling. The spatial and visual world of the project has been built around three core design concepts that reference humanity's long and rich histories of gathering to discuss our relationships with nature.

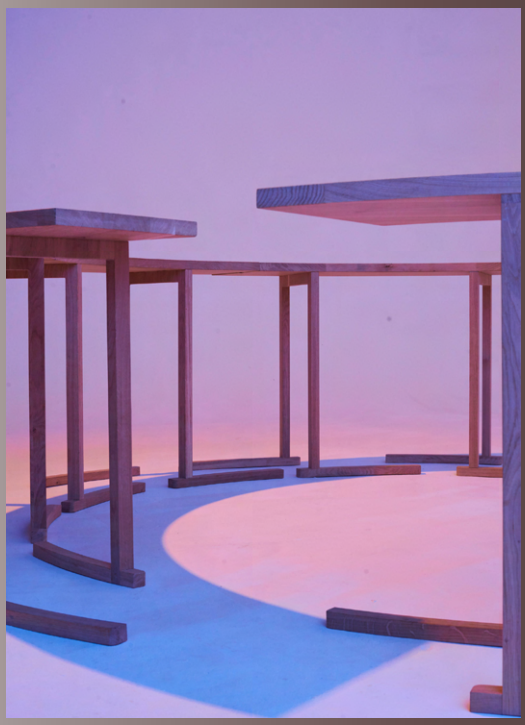
↓ CIRCULAR FORMATIONS

↓ A SEAT AT THE TABLE

↓ A WELCOMING SPACE

GATHERING **G1: CIRCULAR FORMATIONS**

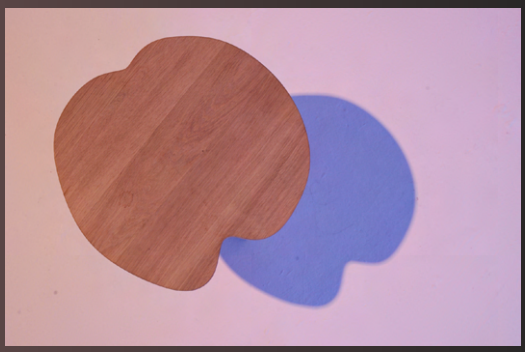
For millennia, people have gathered in circles to discuss the world that surrounds them—sharing ideas, asking questions, establishing meaning and purpose. However, the round table as a spatial trope in global decision-making also evokes the concentration of power in the hands of those who get a seat at the table at the expense of those who do not.
BIO STORIES unfolds around a specially designed round table that is not monolithic, but modular, lightweight and deployable across different contexts. This invites us to take the round table out from behind closed doors and into shared, social spaces.

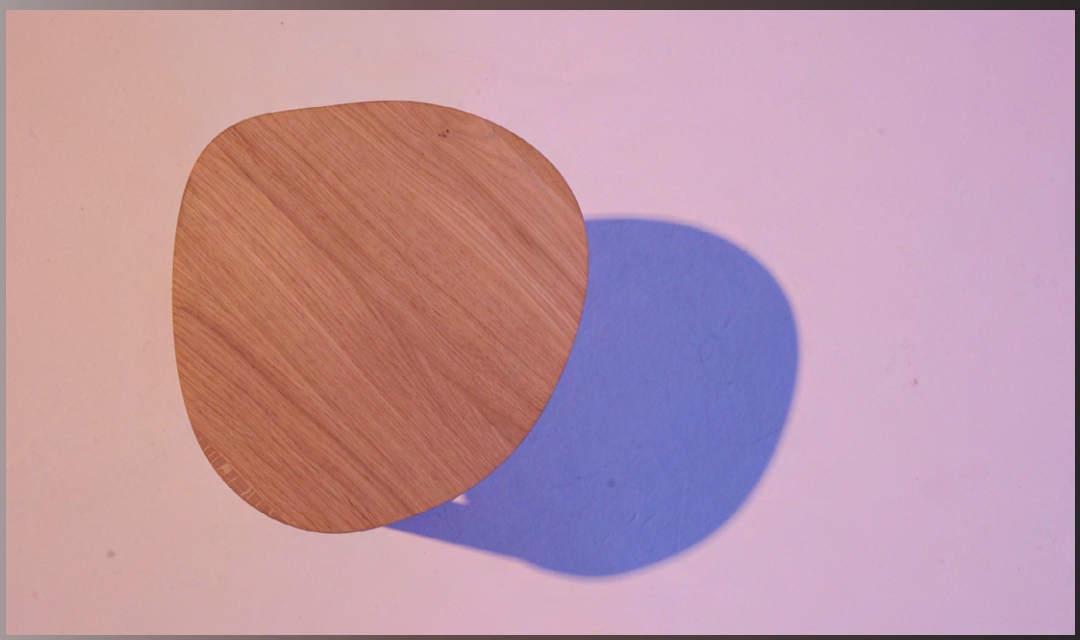


Round Table, 2021. Designed by Faber Futures for BIO STORIES (Eindhoven).
Commissioned by Dutch Design Foundation for Dutch Design Week 2021. Credit: Toby Coulson.

GATHERING **G2: A SEAT AT THE TABLE**

BIO STORIES empowers participants to place their own seat at the table, breaking down hierarchies and bringing us all to the same level. The stool echoes ancient practices of coming together, offering no more and no less than what is required to support dialogue. When approaching the dialogues, the participants encounter a collective of stools that could be placed throughout the room, creating a different layout and dynamic in the room each time. Leveraging computer-aided manufacturing, each stool is unique in form, and the collective can be expanded for further iterations of the project.

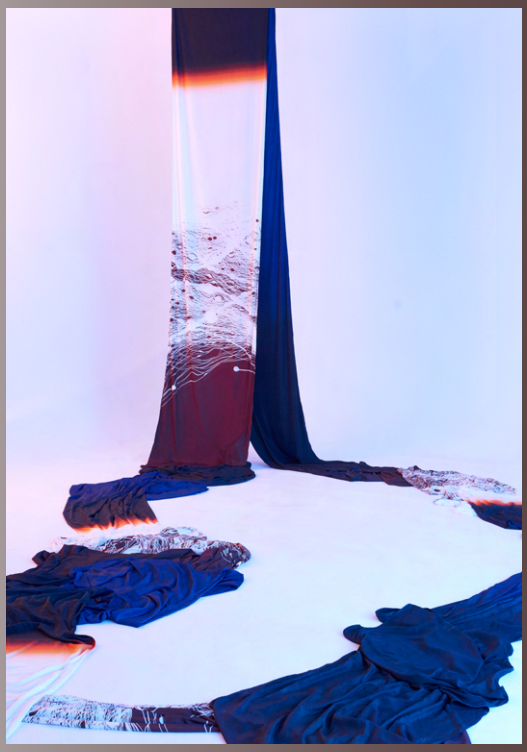


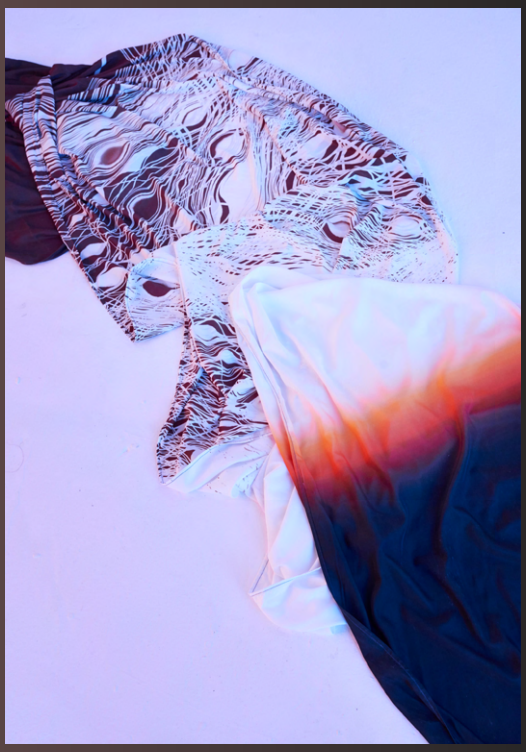


Stools, 2021. Designed by Faber Futures for BIO STORIES (Eindhoven).
Commissioned by Dutch Design Foundation for Dutch Design Week 2021. Credit: Toby Coulson.

GATHERING **G3: A WELCOMING SPACE**

BIO STORIES is framed by a continuous flag, which stands not as an emblem from the narrative of the nation state, but as a symbol of the hidden networks that embody and sustain the interdependency of nature. Textile architectures that communicate intention and position have a long history of holding space for dialogue, celebration or communion—our flag for nature sits in this lineage and becomes both a beacon for the gathering and a comforting backdrop.

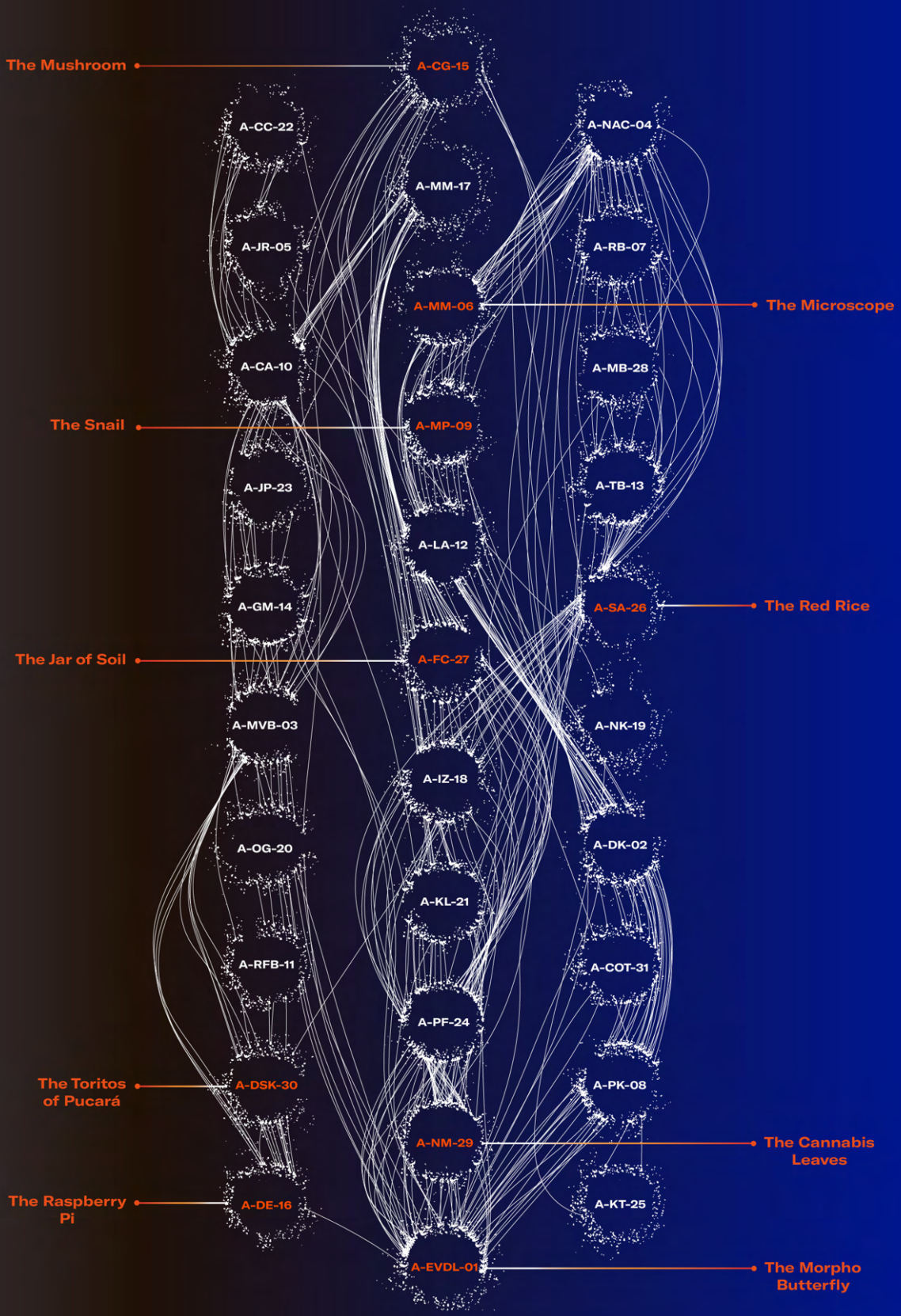




Flag for Nature, 2021. Designed by Faber Futures for BIO STORIES (Eindhoven). Commissioned by Dutch Design Foundation for Dutch Design Week 2021. Credit: Toby Coulson.

THE MUSEUM OF SYMBIOSIS

by Claire L. Evans



THE MAIN GALLERIES

The Main Entrance

The plaque is easy to miss. Most people wander into the Museum of Symbiosis in a daze, awed by the building's strangeness. The walls, for one, are vertical. It is not the lazy winding climb of an oak tree, or the bobbing edge of a blade of grass whispering in the breeze. It is an uncanny vertical—a mathematical straightness that is grating to behold. The floor is flat, meeting the walls at alien angles. It's difficult to trust these trick surfaces, with their hostile impermeability. Not when you are accustomed to slime.

> The rest of the world is a feast for the senses. The rough, dry textures of desert chaparral. Dark stones mattressed in moss. Electric orange mould. Dry riverbeds, carved anew every season by the fanning course of mountain runoff. Cool sand. Hot sand. The fragrant loam of the forest floor. But here, in the Museum, the floors click when you walk on them and the sound of your footsteps echoes across the galleries. Outside is a riot of birdsong. Outside the air smells of mango and compost. Outside it is monsoon season, but beyond the Museum's doors the humidity peels from your skin like an orange. You enter the deafening coolness of another century. The Museum feels like a time capsule.
>
> But, of course, that's exactly what it is.

You'd know that already if you'd read the plaque at the entrance—a plate of embossed brass flush in travertine marble. Over the centuries, the footfall of visitors has softened the letters, reducing entire sections to smooth planes of gleaming metal. Fortunately, the plaque's contents are reproduced in the brochures neatly tucked by the door, reproductions of originals printed in 2030, in the squiggly sans-serif of that strange and transformative decade. The brochures have been preserved, just as everything in the Museum has been preserved, as a reminder of a moment in human history. It was the moment that made hard verticals obsolete and set life loose again to play across the soft surfaces of the world. It was long before you were born and for that you are grateful.

The Welcome Gallery

In the midst of a global pandemic, on the eve of an irreversible climate emergency and in the early, thrilling decades of a biotech revolution, the human race began to question its relationship to the natural world. For centuries, the most

powerful knowledge-reproducers on the planet had believed in a cosmology that artificially cleaved them from the process of planetary symbiosis that sustains—and defines—life on Earth. This cosmology was powerful. It ordered empires. It built many monuments that are still standing today and many more that have long since returned to the soil. It challenged death itself and facilitated the unprecedented extraction of natural resources from Earth. Many of the living creatures of the planet were lost, some forever; many resources were expended to shelter the powerful from the consequences of their own actions. Not everyone had the luxury of ignorance. Generations of people bore the seemingly endless exploitation of their lands, resources and biological diversity. The future was regarded, by many, with a sense of dread and inevitability.

This is something you were taught in school, but it's an entirely different thing to read it here, in this sterile, angular place. There are images neatly framed on the walls: pit mines carved like upside-down ziggurats into mountain sides. Colourful islands made from something called plastic, tangled in whorls of kelp. Fires. Odd charts. Factories. Sick people crowding hospital hallways. A bare patch of sun-baked soil in the middle of a forest. Piles of boxes. Obsidian ribbon lying flat across a prairie. More obsidian, liquid this time, blackening the white feathers of a duck, leaving metallic prisms in the water. You examine each image carefully. The images are as crisp as the floor is smooth, but you do not recognise the world they depict.

> That's why you're here—to learn. You need to see what it looks like when Earth's life-supporting systems are pushed beyond their breaking points, so that it can never happen again. Other museumgoers mill around the photographs: an older man alone, leaning pensively on the handle of a multicoloured umbrella trimmed with solar flashing, a pair of adolescent twins, kicking and jostling one another and a young family, holding their toddler's runny nose up to the framed images.

All are hushed, save for the occasional gasp and muttered reaction: oh my, what, how ugly, look honey, that's what they called clear-cut logging. Next to the photographs stands a large map

of the Museum galleries. It's dotted with small domed lights that shimmer like bioluminescent bacteria as you approach. You run your finger along the smooth laminate wall as you read the long list of artefacts on display. Each name triggers a light; each light triggers a voice.

ARTEFACTS ON DISPLAY IN THE MUSEUM OF SYMBIOSIS INCLUDE:

A LARGE MUSHROOM, STILL DUSTED WITH DIRT
SPIRULINA ALGAE
A JAR OF SOIL FROM A VEGETABLE GARDEN IN ARGENTINA
A CORAL AND A SEASHELL
A GOURD FULL OF GHANAIAN RED RICE GRAINS
A BRILLIANT BLUE MORPHO BUTTERFLY
IMAGES OF A COOPERATIVE FARM IN THE NETHERLANDS
A COLORFUL GARMENT DYED WITH THE BACTERIA STREPTOMYCES COELICOLOR
AN IMAGE OF A WOMAN ENCOUNTERING AN ODD BIOLOGICAL FORCE
A 17TH-CENTURY MICROSCOPE
AN ANIMATION OF A CELL
A LIGHT FIXTURE MADE WITH DANDELION PAPPI
AN IMAGE OF A SNAIL CROSSING A SIDEWALK
A WHEEL OF DUTCH CHEESE
SYNTHETIC RHINOCEROS HORN POWDER
A VIAL OF PATCHOULI-SCENTED PERFUME MADE WITH ALGAE
A PHOTO OF A WORKER IN FRONT OF THE NEW YORK STOCK EXCHANGE
IMAGES OF FRUIT AND FLOWERS FROM TRINIDAD
EYEGLASSES
AN IMAGE OF A STATUE SHAPED LIKE A BACTERIOPHAGE OUTSIDE MAKERERE UNIVERSITY IN UGANDA
CANNABIS LEAVES FROM DURBAN, SOUTH AFRICA
A PAIR OF HOMEGROWN BUTTERNUT SQUASH
A TISSUE CULTURE INCUBATOR
A SMALL ENAMEL PIN DEPICTING MESSENGER RNA
A BIOBRICK
AN ASTHMA INHALER
A SMALL RASPBERRY PI COMPUTER

STAKEHOLDERS

In its multiplicity, the Museum evokes another time capsule, from another age entirely: a 12-inch gold-plated copper disk containing recordings of bird calls, whale songs, music from human cultures and some 55 greetings in a range of languages, alive and dead. This impermeable monument is unknown to you and it will remain that way as it travels on its lonely journey beyond the far reaches of the solar system. Perhaps it has been taken up by the alien intelligences it sought. In those recordings, an Arabic speaker greets humanity's "friends in the stars," while the Nguni and Sesotho speakers call to "great ones" across the distant cosmos. All of this would strike you as quite silly, if you heard it. There is abundant intelligence right here on Earth—friends, great ones, allies and companions alike. It has been the work of centuries to make contact with these other minds. The first breakthrough was to stop speaking and listen.

The Main Galleries

It was an unsustainable existence. Everything was global but nothing was connected. Life persisted but did not flourish. Eventually it was discovered that the cosmology itself was at fault. It had—in fact—always been a fiction, designed to justify the pillaging of the planet for a privileged few. This became obvious as chemistry, biology, computer science and engineering converged into a new field called synthetic biology and humanity began to try its own hand at creating life. They edited genes. Tweaked organisms. Folded proteins. Sequenced DNA. At first it was more of the same: molecular strip-mining, microscopic exploitation. The benefits of the technology weren't distributed equitably; those with greater access to resources and funding more handily reaped its rewards. But the organisms had a strange power. They did not always do as they were told.

You have wandered into the main galleries of the Museum. In front of you stands a forest of white plinths, each capped with a temperature-controlled dome. The artefacts are safe here, eternally preserved. The air in each dome is continuously monitored and

scrubbed clean by an army of microscopic living sensors.
A skin of bioluminescent bacteria bathes each artefact in warm, ambient light. They look beautiful, safe in their hermetically sealed tombs, but the objects in the Museum do not quite make sense to you.

Why were they selected? After all, the world of before was a world of objects. There were more human-made materials on the planet than biomass. Everywhere there was asphalt and airplanes, toothbrushes and toys. You've seen the images: beaches strewn with successive tides of plastic bags, handbags slashed and thrown away in dumpsters, cathedral-sized warehouses filled with everything from shoelaces to bicycles. Plenty of objects from this era have survived into the present age—repurposed, where possible, into useful things. But these artefacts are different. They do not serve any purpose but to teach.

The Mushroom

You are standing in front of a tawny oyster mushroom when a soft voice begins to emanate from the plinth. "My grandmother was over 100 years old when I knew her and we lived in a village," the voice begins, smiling with memory. "We didn't have much and our favourite time of the year was the rainy season. She would sit under a tree and as a little girl, I would run around and collect all different types of mushrooms I could find and bring them to my grandmother." As the mushroom in front of you spins suspended in air, you listen to the voice. It is the voice of Chido Govera, whose name means passion in her native Shona. It has been many centuries since Govera first learned oyster mushroom cultivation and taught it to her surrounding communities in the Eastern montane forest-grassland mosaic of the country once known as Zimbabwe. Three generations have passed since her work promoting the sustainable production of mushrooms transformed waste into food, income and dignity for countless people. Indeed, much has changed since she selected this mushroom for display in the Museum of Symbiosis, but you know Govera's name. Everyone does.

You settle onto a hard bench and listen as she shares her grandmother's wisdom: never close the door on the forest. Always leave a little bit of the mushroom stalk in the ground. Mushrooms do not rot. Poisonous mushrooms are just as important to the ecosystem as edible ones. Mushrooms and other living things are not individuals—they all exist, as we do, within a greater whole. "Science tends to focus on the sterile version of nature," Govera's voice is saying. "It's missing the gods grandmother used to

Image courtesy of Chido Govera.

bring in. It's missing the basic things... like using the right language, the language that shapes you into a respectful human being."

Facing the challenges of the 21st century required a complete re-evaluation of what it meant to conduct science, what counts as scientific knowledge and who was entitled to be a scientist. For centuries, the pursuit of science was undergirded by the Enlightenment belief that nature itself represented an archaic state from which "rational Man" had, in the progression of history, escaped. This enabled a colonial logic differentiating the 'primitive' from the 'modern.' Upon this basis, European colonial societies accumulated enormous wealth and power by extracting labor and resources from the people and ecosystems they deemed primitive—often justified by science, if not explicitly in its name. When they encountered traditional knowledge systems inconsistent with this worldview, they deliberately stripped them of value.

It's moving to be here, in the presence of something so simple and so sacred. Listening to Govera's voice, you begin to understand why this building takes the form it does. If it were as alive, as iridescent and shape-shifting as any other building in the city, it would be impossible to appreciate the courage of the generation it commemorates. The radical hope it took to imagine—to demand—the world you take for granted today. Nothing was green then. Nothing was soft. Surfaces were disinfected. Technology was mindless rocks, polished to a glassy finish. Life was potted plants and zoo animals. Life was thirsty saplings in highway medians. Life was an enzyme in a factory. Life was something to conquer and capitalise upon. Life was dying.

Colonial logic persisted long beyond the fall of individual empires. In the 20th and 21st centuries, corporations accumulated the wealth and resources of entire nations using similar patterns of domination and control.

Recognising and undoing these patterns required first re-learning what traditional knowledge already taught—that humans, animals and ecosystems are not mutually opposed—and then demanding a political transformation to reflect this worldview. This required imagination and effort from scholarly and activist communities around the world. But it was essential to the survival of the human species, to say nothing of its fellow travellers on Earth. By combining the wisdom of traditional knowledge systems with the expansive capacities of modern science, humanity was able to experience a deeper awareness of the living world—and, finally, to untether science from its extractive history.

Ancestral knowledge—Govera's "grandmother language," among many other traditions—helped humanity learn to rejoin the world. It did not exclude technology, nor did it reject scientific inquiry; it made use of technology where appropriate and grounded scientific inquiry in matters of ritual, purpose and care. Like the spidery threads of mushroom mycelium, it formed a network beneath the surface, densely interconnected, waiting to transform the poison of the intervening centuries into food. It was held by grandmothers and great-grandmothers for generations, until the land was returned to its rightful owners, who were always scientists too, who brought the knowledge of deep time to bear on a changed and changing world. Mushrooms do not rot.

Govera's voice falls quiet as the light emanating from the mushroom dome slowly dims. You sit in the peace of the gallery, your unfocused gaze adrift. Another dome warms along the opposite wall, beckoning you closer. You walk diagonally across the room, and as you cut across the gallery you see that the plinths have been planted in neat rows, as crops once were. Neat corridors of white space pass your eye like marching soldiers. It's unspeakably strange to you that people would take things away from where they come from in order to entomb them under glass. You've never seen anything like it. It lends the Museum an uncanny quality, a wrongness. Everyone knows plants grow better together.

The Microscope

The next artefact is unlike anything you've ever seen. It's very small and fashioned from a plate of weathered brass. At the centre of the plate sits a bead of glass no larger than a raindrop. Unlike the mushroom, which is ancient, this artefact is merely very old. *You* consult the brochure and learn that this is a microscope designed in the late 1600s by the Dutch scientist Antonie van Leeuwenhoek, one of only 10 in existence.

> Through this simple handmade lens, van Leeuwenhoek met the world's hidden actors: the panoply of single-celled organisms animating everything from pond water to dental plaque. The "animalcules," as he called them, that could be found in falling rain and carried by the wind and floating alongside the dust in the air. How strange it must have been to find life hiding in air and water. To glimpse bell-shaped protists, nematodes, spirally wound algae and bacteria for the first time. To discover that the air is dense with seeds, spores and organisms. *You* wonder if it frightened van Leeuwenhoek to discover that his own body was an ecosystem. Or was he overjoyed to learn that he was not one, but many?

As if echoing your thoughts, the dome in front of you begins to speak. This voice is accented with a warm cadence and rolls across the room invitingly. "Through the microscope, we came to realise that we are much more than humans," the voice says. It is the voice of Maurizio Montalti, the famous designer whose fungal materials tiled the floor of your childhood home and every home you have lived in since. "We are, of course, walking biotopes, complex ecosystems that result from the collaboration among many very different types of living beings, mostly tiny and not visible and not perceivable to the naked eye," he says. "These are the organisms that make us human."

> Peering into the microscopic world, Montalti's voice explains, is like looking into a mirror. It reveals an aspect of ourselves that defined us even before we could fully understand it: our multiplicity. Our place in an interdependent web of life with no bottom, no end and no aim but to flourish. *You* examine the bead of glass, a tiny portal into that web. Van Leeuwenhoek held his microscope against a candle flame and gazed into it until his eyes hurt, as mystics once lost themselves in polished stones and mirrors, seeking beyond the visible. *You* try to imagine yourself in van Leeuwenhoek's shoes, standing on the outside of nature, looking in. It was a stance he would share with generations of scientists to follow.

Image courtesy of Maurizio Montalti.

Science craved order; it named each molecule and placed every living thing into a tidy taxonomy. Everything had its place in a great chain of being. For many years, scientists believed life to be a competition, one that humanity must win. One crack in this cosmology came from a biologist, Lynn Margulis, who saw evidence that eukaryotic cells emerged from the gradual symbiosis of mutual antagonists. She proposed that conflict is resolved in the coming-together of things—that cooperation, interaction and mutual dependence drove evolution, and not, as had been previously believed, competition. This seemingly new idea was, in fact, very ancient, forming the cornerstone of many Indigenous cosmologies. In the sciences, the heresy lost its sting with time. As biologists learned more about living systems, it became undeniable that interdependence was key to understanding life on Earth. Cooperation was everywhere: trees in old-growth forests communicated with one another through mycelial webs, sharing resources drawn from the soil and brokered by helpful symbiotic mycorrhizal fungi. Bees fertilised flowers. Fish and anemones scratched each others' backs, partners in the sea, even as the great coral reefs bleached to bone-white around them.

As you read this, you notice that you're feeling warm. It's subtle, but a change in temperature seems to have opened the pores of the room. You take a deep breath and inhale a musky, earthy scent that reminds you of finished compost curing in the sun. You close your eyes and linger on the familiar scent, listening to the voice of Maurizio Montalti. Nature is an active process of entanglement between organisms, he is saying, which we call symbiosis. You understand, of course. Nature is a continuous process of becoming enacted by a plurality of lifeforms. Yes, you understand. Across the centuries, Montalti tells you to accept the implications of adopting processes rooted in transformation and transience. Abandon your passion for eternity, he says. You wish that you could pluck the van Leeuwenhoek microscope from its pedestal and bring it home to

your garden, where the soil is thick with jagged spirochaete bacteria, gossamer threads of fungal mycelium, amoeba, bacteria and protozoa. These are the agents through which death becomes life. You would like to greet these invisible partners, but no matter—they will know you soon enough.

The Snail

Understanding is not always the same as knowledge. One can take apart a clock radio, examine how all the parts work, and put it back together again. This does not, however, explain music. One can examine life down to the cell, even edit genetic information. This does not explain life, or express its fullness. This became clear as, in the early 21st century, it became possible to directly manipulate and synthesise life from its component parts. This was done in order to solve problems facing humanity—problems of waste, nourishment, fuel, health and survival. Life grew easily and healed itself handily. As such, synthetic biology created solutions. But it was not a panacea, because life is also a nonlinear phenomenon. It resists definition by the sum of its parts; it can only be understood through the dynamic interrelation of its parts.

As you wonder what a clock radio is, an image catches your eye from a neighboring dome. You step over and press your nose to the glass. The image has the tinny sharpness of the pictures in the entrance gallery. You smile anyway, recognising its subject with pleasure: a storybook snail, glistening brown. It travels across a gray plane of cement, somewhere in a residential neighborhood of Palo Alto, California. Today Palo Alto is a marshland, dense with wild thorny rose bushes and visited by soft-footed foxes and migratory seabirds. But this image predates all that—the snail is travelling the impermeable surfaces laid by people.

The image was taken by Megan Palmer, the scientist turned policy scholar. Her research into the ways biological science and engineering shaped society in

Image courtesy of Dr. Megan J. Palmer.

> the early 21st century—a century of asphalt, crisis and transformation—led to the creation of this very Museum. Her voice is bright. She speaks of the snail with affection. It's moving from one little pocket of nature to another, she explains, leaving as the only evidence of its passing a silvery trail across the sidewalk. The snail travels along its own thick, thixotropic mucus, impervious to hostile surfaces. The mucus protects the snail from everything, adheres it to anything. It reveals where the snail has been, but not where it is going.

Palmer wonders if she should have lifted the snail in her hands and moved it elsewhere, but she cannot guess where the snail wants to be. "We're not starting from zero intervention," she says. "This little creature is already trying to make its way through our built environment and our relationships are very complex, and I hope that in the future, we keep them complex." She wonders about her relationship to the snail and to all living things—was she collaborator or custodian, appreciator or intervener? This was the question of the age. Many wondered, as Palmer did, how to meet the living world on its own terms, while acknowledging that those terms were changing. Humanity had irrevocably changed the planet. This particular snail had never known a life before sidewalks. To the snail, pavement was natural. What to make of this new nature?

The early 21st century was a time of great contradiction. Never was there more awareness of life as a collective super-organism; never were individualistic interests so valorised. New scientific understanding of interdependence progressed even as the forces of industry ploughed complex ecosystems down to bare earth. Books about the importance of forests and oceans were printed on pulped trees and shipped back and forth across the planet in vessels loud enough to drown out the songs of whales. Understanding of climate systems was so precise that scientists could model every raindrop and predict global temperatures decades hence—and yet humanity did little to change its behavior. These contradictions were so puzzlingly intractable that many people believed the only way to transcend the binding conditions of the present moment was to escape the present

entirely. They idealised old ways and sought to trace the shapes of technology in nature itself. But they could never go back. Everything had changed, and the only way to ensure a future was to take a long and unflinching look at the present.

It took two weeks' travel on the solar trains to arrive here from your village. From your window you saw wondrous things. A cohort of flowerwalkers travelling barefoot along the rutted roads of your province, sowing the springtime wildflower seed along the land's storylines. Farther afield, the wandering islands of the Remediation Archipelago, their shoreside lagoons matted with rich blue-green algae; the famous Tree of 1,000 Fruit, in full bloom, branches heavy with a dizzying gradient of pink blossoms; the tangled abundance of the university Milpa; the canal villages of the south, where jewelled carp traveled kitchen waterways. The great cities of the 21st century remain, albeit transformed; the rest of the world is a constellation of villages, communities small enough to maintain meaningful connections between people and just large enough to sustain themselves. Migrating butterflies and birds followed the train, riding its thermal currents, dancing with the glittering nano-insects monitoring the air. They dispersed as you slowed to cross a fairy ring of fungal waste-processing villages encircling the capital city, which came into view like a mirage, all shimmering buildings and big messy gardens thick with bees.

> In the Museum, you return your attention to the humble snail, traveling across the sidewalks of ancient Palo Alto. For that snail, there was no before, only a now. For the humans who built the sidewalks, there was no before either—only a now and, hopefully, with some effort, audacity and care, an after. Behind you the generations have left their own silvery trail through conflict and crisis. Through change, chance and emergence. Through harrowing scarcity and synthetic abundance. They moved with the slow confidence of the snail through it all, safe on the impermeable path they created for themselves. It was a long journey, from one pocket of nature to another, but they made it. And so have you—here you are, in the city, in the after, which is your now.

The Red Rice

You pause to examine a woody calabash filled with rust-colored grains. "This local rice is a short grain and it's red," the voice of Selassie Atadika explains, matter of factly. "It's higher in nutrients

Image courtesy of Selassie Atadika.

than imported rice and does well in highland areas. It does not require a lot of inputs and fertiliser, and does not require too much water to grow." Atadika—a Ghanaian chef known for her New African cuisine, drawing from traditional ingredients like this red rice—speaks of food sovereignty with an eye to the future.

> Traditional rice dishes in Ghana, she explains, are often prepared with imported Asian rice, which is less nutritious and requires more fertiliser than the Indigenous grain. "Much of what we're doing is still very much related to the extraction of cash crops and the defamation of our Indigenous agriculture," she says. "It's important for us to understand how to feed ourselves and how to be able to put money back into the economy, and how to create sustainability by eating what grows traditionally, naturally, better, in the soil that we have." Red rice is undervalued because it produces less yield than white rice, she explains. But the white rice requires more fertiliser, which, in the long term, damages soil health. "What is considered success in the short term might actually mean destruction in the long term," Atakida says. Understanding value requires an awareness of the entire picture—the past and future of an ecosystem as well as of its human caretakers.

Everyone hopes to visit the Museum of Symbiosis at least once in their lifetime. When it was first built, people came to the Museum as a way of making sense of the changes they were experiencing around them—seeing these everyday artefacts so carefully protected helped people to demarcate the end of one era and the beginning of another. Returning to the Museum years later, they found themselves explaining things they'd once taken for granted to their incredulous children and grandchildren. Over the centuries, people have come here for different reasons—driven by disbelief, curiosity, or spiritual fervor. Although it's considered common knowledge today that the Museum commemorates a seismic change in human values, some scholars of the Symbiotic Era have suggested that the Museum itself created the world it hoped to bring about. It has been proposed in several papers and academic symposia that the Museum of Symbiosis has an 'incantatory psychogeography'—that it precedes the change it commemorates. It's a strange theory, but it does make sense. The Museum's voices, replayed for visitors in perpetuity, are so keenly prescient that it feels as though they must have spoken reality itself into being. Their once-radical truth feels almost mundane.

> You have to force yourself to remember that these voices were recorded in the early 21st century. Today, their perspectives are as self-evident as a flower turning to face the sun, but they were once seen as transgressive, questioning—even utopian. It's only

> when the recorded voices speak alien phrases like ‘the extraction of cash crops’ and ‘the defamation of our Indigenous agriculture’ that you understand this fully. One of your schoolteachers once told you to have some sympathy for your ancestors. They nearly had it right, she explained. They understood that living things had value, but they didn’t know how to measure that value, or how to speak of it. The trouble came from their system of measurement, which they called money.

Pre-Symbiosis, attempts were made to measure the value of the living world using numbers that could be understood by the market: the yield of a rice crop, the economic value of a forest per acre, the worth of a wetland or a mangrove swamp expressed as a form of natural capital. Of course, the most valuable things in the world resisted such calculus. A mangrove swamp produces timber, it serves as habitat for birds, it supports cultural traditions like fishing, it sequesters carbon, it protects the shoreline from erosion and the neighboring human communities from storm surges. How to quantify such expansive benefits? How to square all of these inputs with the mangrove swamp’s own nature—the way it simply exists in its own place and time, eternal, irreplaceable?

> These things have their own protected status now, like people. Their value is not measured in terms of market price or productivity. Instead, like clean air, wild fisheries, caregivers, public parks, social equity and quality education for all, they are considered public values. Such outcomes—each as unquantifiably good as the mangrove swamp—are sought directly by the communities who benefit from them. In a process of imaginative co-creation, they gather to ask not what problems should be fixed but rather what kind of society and world, they would like to live in. This is how collective visions are made explicit and shared missions formed. What was once solely the role of institutions to articulate and enact is now equally the purview of communities, which are far more resilient and adaptable to change. The successive disasters of the late pre-Symbiotic era galvanised this awareness: in the face of exponential growth and ecological disruption, those who fared best were those who organised and worked together.

Value takes many forms. It also looks like the package of seeds you’ve brought in your suitcase to the city. The seeds include the important medicinal and culinary plants of your ecoregion, reminders of where you come from and offerings to those you will meet along the way. What began, centuries ago, as a process of rematriation—the return of heirloom seeds to their native soil—has become a traveler’s custom. Seeds are the language of place. They are also carriers of

community knowledge. Your grandmother's garden laboratory has created some interesting specimens this season—a hyper-pigmented violet and a 'talking' maize that spells out messages through its multicolored kernels. After you leave the Museum, you will bring her seeds to the library in the capital and return home, you hope, with some new plants for her. Perhaps you can bring home red rice, too.

The Jar of Soil

As the dome containing the red rice slowly dims, you hear a voice. "You have seeds, I have soil," it offers. At first you think it's the young family you encountered at the Museum entrance, who—their toddler's runny nose now wiped clean—have trailed behind you into the galleries, holding hands and chattering to one another in the sing-songy dialect of the capital province. "I think that both always go together," the voice says, and as you dial your head around to find its source you notice an open door leading to the next room. Following the voice through the door, you discover a small jar of soil, rotating in artificial suspension above the floor. You hunch over the jar to examine it more closely. "If you have a seed and you don't have the soil," the voice says, "you can't do anything."

> The jar is made of glass—the old kind, with a screw top lid. Within the jar the soil looks dark, damp and rich. It's nearly 300 years old, of course, but the Museum maintains the life of this soil through regular ministrations of organic matter. The microorganisms currently present in the jar are ancestors of the original microorganisms. But are any of us really the same, from one year to the next? As we shed dead cells and host generations of microbial communities in our guts? A system may change, but if its internal relationships remain intact, it persists—resilience is not about maintaining an image, but a pattern.

The original soil was dug from a garden in Argentina, where the mother of a digital artisan named Fernando Castro once grew vegetables. Castro grew vegetables too, in his way, by helping subsistence farmers in Argentina transition to sustainable agroecology. He built tools to help them measure and monitor the soil's health, because Castro loved soil and appreciated the vast life it contains. "It's a small world in itself, this little bit of soil," his voice offers, across the centuries. "It's a small world with many worlds inside."

> The Museum brochure speaks of cosmologies. It explains that, pre-Symbiosis, people believed themselves to be separate from the living world. Superior, even. From there followed the assumption that humanity was entitled to dominate the rest of the planet, and to treat the living world as a raw resource to exploit.

Image courtesy of Fernando ‘Nano’ Castro.

> You remember the photographs of mines and clear-cuts solemnly framed at the Museum's entrance. Today there is nothing so formal as all that: you just sit with the world, sharing an easy and natural complicity. Nothing is forced to act against its nature. Life is available to commune with at all scales, from Petri dish to ecosystem. Everyone is a scientist, in their own way, since everyone seeks the best way to interact with the life surrounding them. To perceive, too, what they themselves are made of. If your cosmology had a shape, it certainly wouldn't be a straight line. It might look like a spiral, or like a jar of soil: a small world with many worlds inside.

The generation that created the Museum of Symbiosis seemed to think a great deal about the future. It weighed heavily on their minds; it felt hot, violent and terribly brief. They felt themselves to be in a race against time, and were desperate to find solutions that might buy them a few more years, like crops strong enough to withstand drought, or vaccines to combat rapidly mutating infectious diseases. With every success came unanticipated failures: the new crops survived parching hot summers, but, planted in great monocultures, were vulnerable to disease. The vaccines were not distributed equitably around the world, turning entire populations into incubators for more and more aggressive variants of the very diseases the vaccines were designed to protect against. Some days, this lack of consideration makes you livid. How could your own ancestors have been so short-sighted? Other days, you remember your own failures and give them a little grace. When you fail, the important thing is to keep trying. And try they did.

> You don't imagine that your future will be terribly different from your present. After all, yours is a practical reality of cyclical economies, regenerative processes and objects designed to return to the land with minimal interference. Your consideration of the future is simple: you hope to leave the world as you found it, if not in better shape. Your six-month shift in the remediation corps begins next spring, and it will take you to a former electronics disposal site in the desert—a place where the soil is still poisoned three generations after the global E-Waste ban. This, too, makes you livid. Your ancestors left you to clean up their mess. Did they think the future would end before you were born?

Before you left for the capital you asked your grandmother to tell you about the Museum. You'd heard stories: that it was overwhelming, best taken in over the course of several days. You were worried that you would miss something important. It's not often you get the chance to come to the capital. Would you have the time to examine each artefact with care? Your grandmother put down her pipette and smiled. "That isn't how the Museum works," she reassured you.

“It’s not a chore, or a task to be completed. You must simply enter with an open mind and let the artefacts choose you. Everyone is drawn to different artefacts, and it’s as rich an experience to see them all as it is to sit with only one.”

She once spent an entire day at the Museum deep in meditation with the tissue culture incubator, harmonising with its ambient hum. But that’s her nature, not yours. You’ve always preferred to make connections, to understand one thing in the light of another. You suppose that’s why you’ve taken such a meandering path through the Museum, building your understanding of each artefact cumulatively.
We are all the product of our surroundings, defined by our place in a web of human and more-than-human relations. After all, what is soil without a seed?
And what is a seed without soil?

The Toritos de Pucará

As you leave the soil room, a pair of ceramic statuettes catch your eye. They’re standing next to one another, shoulder to shoulder on a slender plinth nearly a full metre taller than its surroundings. Their horns and hooves are tipped with gold and their flanks are covered with delicate petals of red and blue paint. They peer down over the rest of the room with an authoritative air—guardians, perhaps, of the gallery’s precious artefacts. “They are Toritos de Pucará,” a new voice explains. “They’re from a place in the Andes in Peru called Puno.”

This is the voice of David Kong, a synthetic biologist and social activist best remembered today as someone who helped countless students of the life sciences to organise and run their own community biotechnology labs. Biotechnology, he believed, should not solely be in the hands of powerful institutions, research labs and corporations. Like biology itself, it should be everywhere—in gardens, homes, schools and communities. Kong and his peers knew that building an inclusive network of biotech leaders and empowering them to solve problems creatively would lead to world-changing innovations from the bottom up. He was part of a global community of do-it-yourself life science enthusiasts who studied the history of movement-building. From their mentors and teachers, they learned how to leverage their collective values towards a shared purpose, putting pressure on governments and public and private institutions alike, demanding that the benefits of industrial biotechnology be shared equitably, and that proceeds

Image courtesy of David Sun Kong.

be reinvested into their network of community labs. The bulls, he explains, were a gift.

For centuries, the Toritos de Pucará have been protectors. In the Andes, they're often spotted sitting on rooftops and standing at attention near the entrances of homes, guarding families and ensuring their happiness. But in order for the little bulls to function in this capacity, they must be given as a gift. That's because their power comes from the act of giving, an intentional gesture that imbues the bulls with meaning. This is the special relational energy created through gifting and gratitude, Kong explains, which activates an object and gives it a social context. The bulls have this energy two fold—they were given to Kong and, in turn, Kong gave them to the Museum. Perhaps he was hoping to protect the future.

For a long time, it seemed as though the more humanity learned about the living world, the less it understood. Exciting breakthroughs led to stagnation. Researchers touted world-changing innovations that never seemed to arrive. Novel biotechnology solved problems—but those solutions often created new problems. It wasn't for lack of caring. The synthetic biologists cared very much and often discussed how to deploy their discoveries responsibly. In laboratories and universities, they shared ideas and spoke of democratisation. Knowledge should be free, they said, and biotechnology should be made personal. No, it wasn't that humanity didn't care enough; it was that they cared in the wrong way. Rather than love, their attentions emerged from fear—the fear that they might lose valuable biodiversity before it could be captured. The fear of annihilation. The fear of losing control. The fear of losing money. They cared about the living world, but they did not care after the living world. They did not take care of it.

Kong asks, "Could you imagine a world where we actually are honoring the organisms that provide us the life-saving compounds and therapeutics? What does a world look like where gifting and gratitude are central to how we engage with the living world?"

You don't need to imagine it. At your local community biotechnology lab, where everyone can be a scientist, rituals of gratitude are part of everyday operations. The cells you work with there are no different from the animals and plants you tend and forage: you never ask for more than they can give, and you always acknowledge their role in the process. It's the same with machines. You smile, remembering last month's celebration at the biofoundry—how your friends connected the robot biomechanics to the bellows of a custom-made concertina and how you all danced, laughing, into the night, to the music it created. Gratitude is a form of care, and care begets gratitude. None of this is finite. Quite the opposite: it only grows stronger and more abundant with time.

The Cannabis Leaves

You find a hard bench against the gallery wall and take a rest. Your mind begins to wander, and you think of the night market you'll visit tonight, the flute music, the street vendors pouring syrupy apricot juice from speckled silver goblets, the nubby local silks dyed blue and purple with soil-dwelling bacteria, the fruits you'll sample from garden laboratories across the region. The capital province is drier than your village, with crisp winter winds that whistle along the hillsides; you've heard the wine here is sweeter. You'd like to take a bracing dip into the salty coastal lake, whose waters are soft pink and dense with brine shrimp. In fact there's quite a lot you'd like to do while you're here in the city. But the Museum of Symbiosis has more to tell you.

There is a nervy presence in the room, a quality of microscopic aliveness, like a hummingbird's heartbeat. It's enough to get you back on your feet with a start. You don't see anyone else in the room—the young family has wandered off towards a display of seashells in the next gallery—but still, you sense that you are not alone. The voices you've awakened with your presence have continued to talk to one another, to themselves and to you. Their urgent whispers echo across the room and across time. As you approach different artefacts, new voices join this chorus: "I think we need to understand we do not exist in isolation from other species," one says. "I think a bit of humility is very important for us," responds another. "What if we let biology speak?" asks a third, and from there the questions multiply: What does nature mean to us? What has life come to mean to us? How do we see the future? How can we scale up? How can we scale back?

Credit: jcomp via Freepik.

If you hold still and listen deeply you can isolate one voice from the din, like choosing to watch a single blade of the ceiling fan as it spins. But the overall effect is of a kind of song, a jangled round of spoken words. The polyphony reminds you of home.

The Symbiotic Era began with a thrilling confluence of ideas. Everything came to a head in 2030. Although this date is now recognised as the official dawn of the Symbiotic Era, or Symbiocene, it was not a single event, but a weaving-together.
By the end of the 2020s, scientists had discovered that it was more effective to work with life than against it. Evolution had already created countless highly competent organisms. When researchers took the time to understand each in the full context of its evolutionary history, it became possible to enlist wild collaborators in all manner of projects.
A similar shift in thought occurred in synthetic biology labs: although the discipline of synthetic biology had initially emerged from engineering, inheriting that field's emphasis on systematic control, it became obvious to the synthetic biologists that life resisted any attempts to constrain it. It was more productive to understand and harness life's existing strengths: its open-ended creativity, ceaseless adaptation and an indomitable drive to flourish.

One voice speaks with a dry frankness that cuts through your reverie. You wander towards a bright green cannabis leaf—a wild plant with slim, rangy leaves. As you examine its delicate veining, you listen to the research scientist, academic, corporate advisor and entrepreneur, Dr. Nhlanhla Msomi. He was president of BioAfrica at the dawn of the Symbiotic Era, and helped to shape the policies that redefined value for a new age. With fondness, Msomi is describing the herbal medicines his grandmother crafted for him when he was a boy, from the cannabis plants growing wild around his hometown of Durban, South Africa. Once he left his grandmother's side, he was forced to use asthma inhalers instead of the traditional cannabis steam she prepared to soothe his lungs. The 'modern' medicine never worked quite as well. It was missing something.

> “When we talk about medicinal plants, we use a Western paradigm,” explains Msomi. “We use the notion of an active ingredient—whereas a lot of the Indigenous knowledge systems tend to work in a synergistic manner.” Science allowed the people of the 21st century to isolate and examine plant compounds in isolation, and they often found success creating medicines drawn from these compounds. But flavour, nutrition and medicinal potency emerge from the complex interrelations of many compounds, which themselves emerge from an evolutionary history spent in constant interaction with an ecosystem. Like people, plants do not exist in isolation. “The value that is embedded in the Indigenous knowledge system is not in the actual unit, it’s in the interactions,” Msomi explains. In the Global South, he adds, people tend to use plants in a synergistic manner, using the whole plant, rather than just a single compound that can be isolated and turned into an economic unit. They also consider the interactions—the relations between plants and within the environmental context. And they situate the whole in rituals of care.

You understand, then, why you were drawn to his voice. You are standing in the centre of a gyre of knowledge, in the form of plants, artefacts, voices and memories. It is a living time capsule. And although each artefact has a voice and a point of origin, there is something transformative in their collection as a whole. They do not speak in isolation. That is the power of the Museum of Symbiosis: the story it tells is collective, like history itself, like life on Earth, like the cells in your body, like the countless agents pushing and whirling through this world, making meaning, making music, making life.

It wasn’t long before the historians, ethicists and artists-in-residence working alongside the scientists realised that leading with curiosity—taking the time to understand not only what drives an individual organism but the context informing its drives—could be applied to societies as well. People, too, had context, in the form of history, and the stories they told themselves. Certainly humanity could never survive the century if it remained mired in an idealised and myoptic fantasy of its own past. And so it became the essential project of the humanities to frankly assess the here and now in order to more freely

imagine where we might go next. This effort was met with heated resistance by the beneficiaries of history: those whose ancestors had been enriched by the extractive, profit-driven subjugation of the living world and by the devastating exploitations of colonial empire. Had it not been for the existential threat of climate change, which presented humanity with a stark image of its own mortality, the Symbiotic Era may well have been permanently derailed.

The Raspberry Pi

Oh, you recognise this! Your father had one. About palm-sized, soft grey, carved with the outline of a summer fruit. It's a computer called a Raspberry Pi, inexpensive and simple to programme, and the heart of home-built systems everywhere. It was part of the solar rig at home, the last holdover from the oldest part of the system—a rugged little robot that drew solar energy during the day and detached to wander the garden paths at night and weed invasive plants. The old computer was a bit of techie nostalgia but like your father always said, "if it ain't broke...". Until, eventually, it broke. The Raspberry Pi still has a place of pride in your family home, stationed above the hearth with a few other junky, sentimental reminders of a lost age.

As humans became aware that they existed within nature, their interpretation of technology changed. Machines were merely adaptations made by biological organisms living among countless others. Tipping points in biology and synthetic biology flattened once-hierarchical relations between people, plants, animals, ecosystems and micro-organisms. In computer science, in the wake of the great silicon shortage of 2027, it became both practical and economical to develop computing systems with new substrates. Eventually, searching protoplasmic tubes of electric yellow slime moulds would trace more efficient networks; information would be

Image courtesy of Drew Endy.

encoded in plant DNA and propagated in great fields of knowledge; functionalised mats of fungal mycelium would serve as ambient sensors in a biological internet of things; living robots carved from frog cells would conduct tasks too minute and dangerous for people or machines. Although humanity had once been content to push abstract symbols around on devices of glass, mineral and stone, the Symbiotic Era muddled the distinctions between living and dead, animate and inanimate—and finally, thankfully, between nature and people.

The first time you saw your father's Raspberry Pi robot, you were six. You tried to feed it some lichen. A reasonable assumption considering everything you'd seen, by that age. Computers, to you, were already living things, not slabs of silicon. You glance back at the plinth holding that old microscope from the 1700s. These two artefacts don't feel that different to you. Scientists once peered through polished glass at a microscopic world, imagining themselves on the outside, looking in. Over time they came to name every organism they encountered. They measured and organised them all, producing enormous amounts of data. To process that data, they built machines, and those machines became so important that the scientists began to see the world as though it, too, functioned like a machine. They began to see life through the computer, as they had once seen life through a microscope.

> To suit the computer's inflexible world-model, everything needed to be reduced to its component parts. This mechanical mentality manifested itself in language: in synthetic biology, it was common to hear living organisms described as tools, devices and parts. Cells became chassis, genes became software and DNA became an operating system. Scientists spoke of building with blocks in a great factory of life—making and remaking living systems as though they were mere machines. The Raspberry Pi beeps placidly as a man's voice issues from the plinth. It asks, "What is synthetic biology about?" You think: synthetic biology is about facilitating relationships of mutual reciprocity. It's a powerful model for understanding life. It's a way of participating in ancient processes.

"It's about the expression of human intention in partnership with living systems," the voice answers. "It's about speech." You check the brochure. This is the voice of Drew Endy, the American synthetic

biologist. As founder of several open-source biotechnology initiatives in the early 21st century, he helped forge key connections between community bio-labs and researchers around the world, opening the possibility for more people to become citizens of the bio-economy, rather than its consumers.

> Language is important, Endy explains, and so is culture; if we understand synthetic biology to be part of human culture, a form of expression in concert with the living world, then it might be governed as we govern poetry and music. Endy echoes what many of the other voices in the Museum have said during your visit, in their own ways: that human separation from nature is artificial, and that as biotechnology becomes more fully-realised, more embedded within our bodies and societies, this artificial separation will become more difficult to abide. "Increasingly we'll see that we're not apart from things, that we're connected," Endy's voice says. You think of the colony of microorganisms in your sinuses, which turn your mucus bright pink when you contract a respiratory infection—they're not you, but they are part of the multiplicity that makes you. Not apart. Connected.

In the meantime, Endy suggests, the relationship between people and nature is both understood and expressed through language. If we want to change our relationship to the living world, we must also change our language. Can we parent and collaborate with life, he suggests, rather than control and dominate it? Can we grow, rather than build? Can we sculpt, carve and dance with—rather than assemble, code and engineer? A fully-biotic society, Endy explains, mustn't be solely motivated by fear or desperation in the face of dwindling resources. Rather, it can be driven by curiosity and a sense of collaborative discovery. It can even be playful, since play, in both animal and human lives, is an important developmental stage, key to establishing trust and communication.

> Before it finally sputtered out, your Dad's Raspberry Pi robot developed a kind of rapport with the neighbors' barn cat. They both prowled the garden at night. The cat would hide behind the hedgerows, watching the robot make its rounds, wiggling its hind end until a burst of energy propelled it to pounce, toppling the poor robot into the planter beds. Righted by its internal gyroscope, the robot would continue along its way, only to be knocked down again and again. You found it riveting to watch the cat and the robot fumble around, as littermates would. Although they were two very different kinds of beings, they were at home together in a post-natural garden.

The Morpho Butterfly

In the corner of your eye you catch a flash of brilliant color. As you approach the butterfly, its wing flutters, setting into motion delicate reflections of metallic blue. It's the blue of lapis stone; the blue of deep water; the blue of a jungle sky at noon. It's profoundly beautiful and made even more so by the fact that it doesn't exist.

> The blue of the Morpho butterfly does not derive from pigment, but light itself reflecting from the microscopic diamond-like scales covering its wings. You recognise it at once, because your favorite dress is Morpho blue, and your village flag. In fact, Morpho scales are cut delicately into surfaces everywhere. Color from form is an idea borrowed from the butterflies—just as buildings mimic termite mounds, adhesives mimic the toes of tree frogs, and surgeons seal wounds with spider-like silk. Even algorithms are 'ecorithms' modeled after the cleverest adaptations of living systems. Evolution is the process of creative becoming. Humans were the result of this process, but they are far from its end.

You no longer feel as though you are simply a visitor to the Museum, or that your role is to walk a straight line from exhibit to exhibit, nodding gravely as you take in the atrocities—and audacious hopes—of the distant past. Your role is evolving into something more active. The voices envelop you. You have a place in their story and a responsibility to continue it. You begin to feel slightly, dizzily delirious, like a pollen-drunk bumblebee. Staid lines curve. The sounds of the gallery warm your ears. The loamy perfume of soil and fungus grows richer. Without realising it, you have fallen into a trance, your inner wandering guided by the persistent song of voices surrounding you. You decide to succumb to it fully. Certain words appear and reappear in your consciousness with the persistence of mantras: equity, sustainability, humility, solidarity.

The new technologies did not poison and deplete the Earth as the servers, chips and batteries once had. Instead, they were regenerative, returning to the Earth all they had drawn from it, and more. Data fruit trees drew heavy metals from the soil. Mycelial systems transmuted toxic waste into benign edible mushrooms. Algal computers sequestered carbon deep beneath the sea. It became impossible to distinguish between a garden and a computer—and who would want to? Every blooming flower was a node in a great system, processing and expressing the beauty of wild information.

Credit: Fotostudio - All Eyes On You via Pexels.

In your imagination, the neat little domes crack open like eggs, setting the musty air of history loose into the galleries. Suddenly everything leaps into conversation with everything else. Govera's mushroom exhales its spores towards Castro's soil. Palmer's snail nibbles Msomi's cannabis leaves and creeps through history to peer through Montalti's microscope. The butterfly comes alive and flies out the window; bunches of Trinidadian flowers bloom; the rust-red grain cracks and sprouts tendrils of green; a beaker of algae issues a heady patchouli perfume; delicate pappi of a dandelion seed drift through the room as lazily as motes of dust in a sunbeam. In the midst of this hypnotic entanglement, a fragment from an ancient poem bobs up in your memory:

I like to think
(it has to be!)
of a cybernetic ecology
where we are free of our labors
and joined back to nature,
returned to our mammal
brothers and sisters,
and all watched over
by machines of loving grace.[1]

You feel a sudden urge to tear open the Museum and let the outside world in. Surely nobody would stop you—not now—from running across the galleries, pulling the blinds, smashing windows, and inviting the past to mingle with the present. These artefacts should not be hidden away, pinned and preserved like butterflies under glass. The people of the Symbiotic Era knew how important it was to understand history and, where necessary, to correct its imbalances. They also learned to cherish the rich web of relations that define existence on Earth. They celebrated interdependence, or else they never would have survived. They never would have turned the colossally extractive mechanisms of industry inside-out, or made the regenerative processes of the living world available to all. They never would have returned technology to the earth, integrating everything humanity had learned in its troubled journey to maturity back into its source. And they never would have built the Museum of Symbiosis—the first seed planted in a flourishing new world.

You throw open the Museum door at last.

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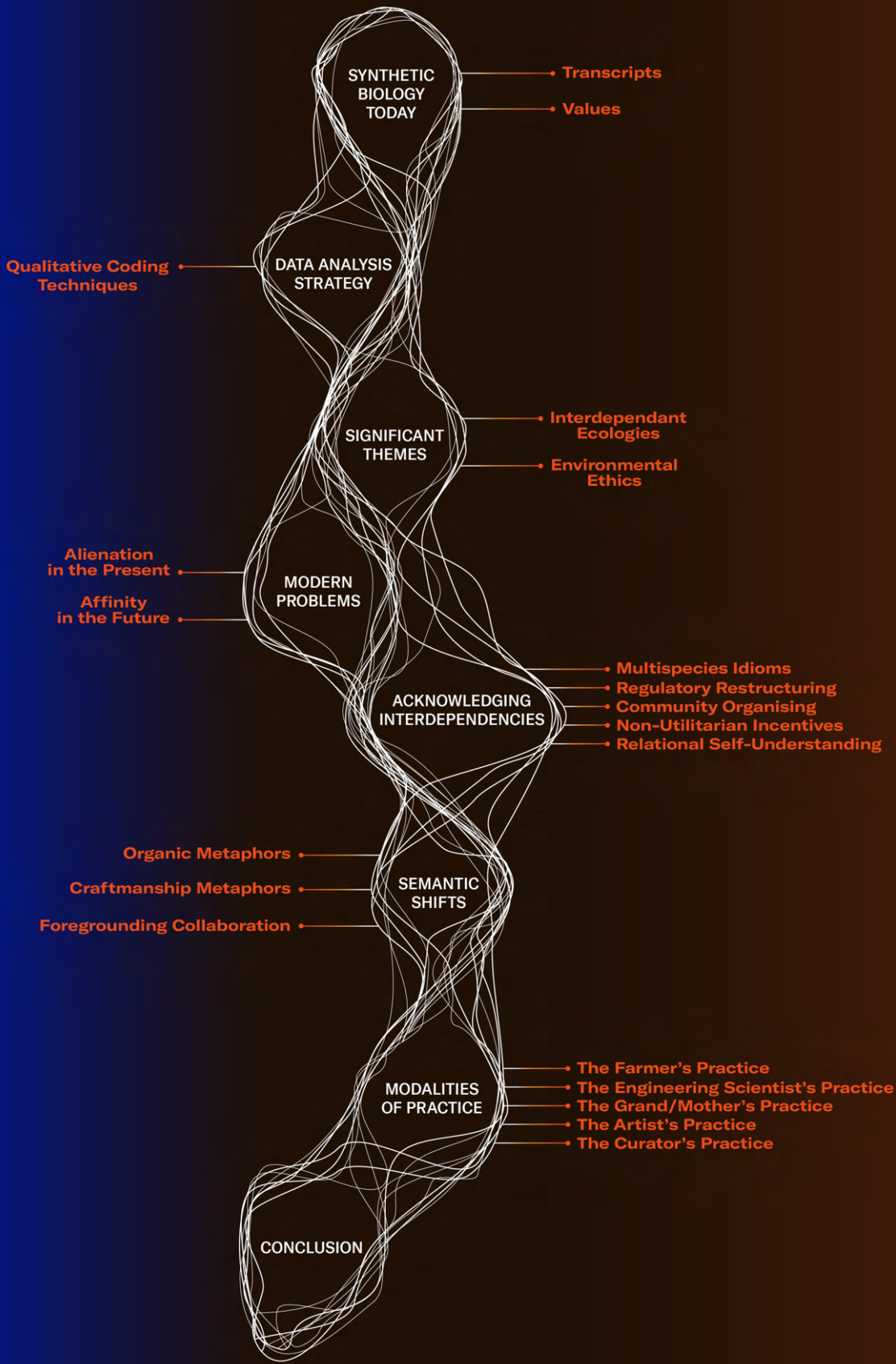
1. Extract from Richard Brautigan's poem - "All Watched Over by Machines of Loving Grace". https://www.theatlantic.com/technology/archive/2011/09/weekend-poem-all-watched-over-by-machines-of-loving-grace/245251/

DIALOGUE SYNTHESIS

by Dr. Melissa Salm



Synthetic biology actively generates new relationships between technology and the living world. While advancing our knowledge of life, it might also transform our understanding of what it means to be human. As the field develops, its intentions and inventions oblige us to question our longest-held assumptions about the relationships between nature, living beings (bios) and humans (anthropos)—rethinking their status as integrated and interrelated rather than separate and discrete.

BIO STORIES embraces this challenge by showcasing the perspectives of selected stakeholders who are reflecting on their own present practices, envisioning ideal futures for synthetic biology fields and speculating on the best approaches to bring those futures into being. Remarkably, nearly every stakeholder expresses a common, core conviction: that movement towards a desirable future demands that we establish new relationships with nature today—relationships that differ distinctly from those of the past. BIO STORIES' stakeholders express this in diverse ways, for each speaker's voice is a unique lens into the field's future trajectory. Taken together, their perspectives provide us with the contours of new languages and ways of thinking, which may guide us towards desirable futures, despite present realities.

Here, we present our findings from a discursive analysis of the BIO STORIES dialogues. Above all else, they analyse how stakeholders' relationships with nature are changing, and identify the values guiding those changes. On one level, this synthesis seeks to demonstrate how the values identified by World Economic Forum's Global Futures Council—equity, humility, sustainability and solidarity[1]—are embodied in stakeholders' present practices and articulated in their future visions of the field. This analysis also suggests that stakeholders are intentionally reconfiguring their relations with nature through orientations to future natures that would expand upon the Forum's values—and potentially require the foregrounding of additional values and views. Ultimately, this synthesis indicates that modifying and reprioritising synthetic biology's guiding values may benefit the field moving forward.

1. World Economic Forum (2021) Revisiting and Realizing the Promises of Synthetic Biology. Briefing Paper. [online] Available at: https://www3.weforum.org/docs/WEF_Revisiting_and_Realizing_the_Promises_of_Synthetic_Biology_2021.pdf.

DATA ANALYSIS STRATEGY

Aiming to identify the multiplicity of practices, values and visions guiding the contemporary field of synthetic biology toward its desired futures, we pursued data analysis of the dialogue transcripts within a framework inspired by grounded theory.[2] Grounded theory is an inductive research method for generating evidence-based findings that are tightly connected to the data. Unlike other research approaches that attempt to confirm preconceived hypotheses or validate extant theoretical frameworks, the grounded theory approach enables unexpected 'theories' to emerge through a process of iterative analysis. Accordingly, our strategy did not seek to solidify the values prescribed in advance by the World Economic Forum's Global Futures Council. Rather, we aimed to identify their various forms and specificities while leaving the possibility open for other additional values to emerge.

We applied three stages of qualitative coding to the dialogues: Initial Coding—remaining open to all possible emergent themes indicated by readings of the data; Axial Coding—categorising the data inductively based on thematic similarity and relationality; and Selective Coding—integrating thematic categories into core theoretical constructs at a higher level of analysis. This iterative process enabled us to systematically compare and contrast storylines across the aggregated data, allowing for grounded BIO STORIES to emerge. Additional details on the benefits of this coding methodology are provided in the section (METHOD).

The synthetic biology field comprises a plurality of perspectives and positions, all of which hold a stake in its future trajectory. We aimed to select a representative, though not exhaustive, sample for inclusion in this project. The themes provided in this synthesis offer multiple possible entry points into a more nuanced conversation about desired futures, what is at stake and how to get there.

2. Corbin, J.M. and Strauss, A.(1990) 'Grounded theory research: Procedures, canons and evaluative criteria', Qual Sociol 13, 3(21). Available at: https://doi.org/10.1007/BF00988593.

SIGNIFICANT THEMES

Perhaps the most prominent theme emerging from an analysis of the BIO STORIES dialogues is an ineluctable awareness that humans are biologically enmeshed in an interdependent ecology co-populated by other, nonhuman beings. It is upon this basis that several stakeholders argue the need to rethink the values driving present practices in synthetic biology. Stakeholders describe looking at climate change, a global pandemic and other ecological consequences of neoliberal economic globalisation and urban sprawl—such as the erosion of biodiversity—as reasons for rethinking the norms and values that currently organise our relations with nature.

The second most pronounced theme is the widespread demand to foster future environments that facilitate greater social inclusion among the field's stakeholders, innovators and decision-makers. This ethical reorientation—to both natural and social ecologies—is a combined result of historical circumstance, scientific advance and political conscience. Synthetic biology fields have become increasingly populated by multiple stakeholders, including scientists, engineers, designers, artists, farmers, social scientists, humanities scholars and activists. They each bring with them different priorities, values and thus different ideas of what the field 'ought' to become.

The stakeholders included in BIO STORIES are grasping for new ways of thinking and speaking about nature. In turn, they give form to a reconceptualisation of the human as a relational being whose ways of knowing and living are formed in a network, or 'ecology', of relationships with other living beings.

MODERN PROBLEMS

Nearly all participants in BIO STORIES describe their orientation to contemporary synthetic biology and its imaginable futures with explicit reference to present conditions of uncertainty, including: rapid climate change, the ongoing COVID-19 pandemic and the potential impacts of these largely human-driven catastrophes upon future forms of living in the Anthropocene. It is within this sombre context that stakeholders articulate their perceptions of changing relations with the living world and speculate on strategies for realising desired futures.

Their depictions of the relationships between humans and nature can be grouped thematically and temporally as: (A) Alienation in the present and (B) Affinity in the future.[1]

Alienation in the Present

Throughout the dialogues, stakeholders describe feeling presently alienated from nature in some form or another. For many, this mood of estrangement is directly linked to 'industrial', 'Western', 'Enlightenment' or 'scientific' ontological paradigms that place the human and nonhuman worlds in artificial opposition.

Nearly every participant concludes that this conceptual divide has been deleterious for both humans' self-understanding and their relationships to the environment. They claim that this particular dichotomisation has permitted ecological degradation in ways that are increasingly impossible to ignore in the present.

Julia Rijssenbeek: *This pandemic is just another wake-up call showing us that we are not separate from nature, and that we should not try to separate ourselves from nature in this modern dichotomy between humans and other life forms, but that we should seek new ways of interacting in the first place. That starts with figuring out new ways to not destroy ecosystems, for instance, which may make us less vulnerable in the future.*

However, feelings of alienation are not solely determined by a prior misconceptualisation; they are also experienced as a consequence of systemic inequities in the modern scientific enterprise.

Nhlanhla Msomi: *In the valley where I grew up, cannabis leaves were available, not as an illegal plantation, it was just part of nature. Cannabis has a bad rep to a point where it's considered illegal. And as a result, what has not happened is systematic plant propagation or even plant breeding of the varieties that have medicinal value! In traditional places, in villages like my own, the way they keep the knowledge is through the propagation of the plants. But the knowledge is not being conjured appropriately, because those who have the means and the resources to conduct the research choose not to do so.*

[1] These categories emerged during thematic co-occurrence analysis, in which thematic relationships between code categories were identified across a set of research questions: How do stakeholders describe human-nature relationships with reference to the present, the past and the future? Thematic patterns between the co-occurrence of codes affixed to passages of text relevant to these questions were identified, ordered according to frequency, then commonality and collapsed into the thematic groups above.

Several synthetic biology stakeholders, whose practices and perspectives are rooted in 'Indigenous knowledge systems', describe being alienated simultaneously from their local biological resources and cultural traditions, both epistemically and economically.

NM: *One of the biggest issues around Indigenous knowledge systems—and I'm pretty much confident that it's the same elsewhere in the East and in other places—is that when we talk about 'medicinal', we use a Western paradigm. And so we use the notion of an active ingredient, whereas a lot of the Indigenous knowledge systems that we tend to utilise as societies—let's say, in the Global South—tend to work in a synergistic manner. And that's why there's not been a lot of success in trying to harvest that knowledge. That's pretty much why the pharmaceutical industry and the scientific enterprise have abandoned their attempts to try understand this Indigenous knowledge system because it's costly if you use a Western idea of what constitutes economic failure. It's not economically active because there is also a big push, even in this country and across the continent, for converting these natural resources to economic units. And it's not going to work in the manner that we know how economic units work in terms of widgets. It doesn't work like that. It does not lend itself to that.*

Stories such as these expose the limitations of global consumer capitalist economic models insofar as they are often unable to commodify the value of Indigenous knowledge and goods, despite their potential to advance biological knowledge, increase biodiversity and open up new bio-economies by privileging more holistic understandings of value, health and life.

Fernando Castro: *Here we have in Argentina many small towns that are saying, 'Okay, we don't want any more poison [for weeds and for pests]. We want our ecology now.' ... I think there is a growing movement towards this kind of agriculture, starting to look at soil as a living thing and starting to think much more about the health of the people around and much less of this economic equation, let's say. It's not only about productivity, but it is also about sustainability. It's also about a good life.*

To reduce these and other forms of biological, cultural and economic alienation in the present, many stakeholders express an urgent need for the field to shift from 'industrial' to 'ecological' paradigms of knowledge and value production.

Affinity in the Future

Stakeholders diagnose a pernicious sense of entitlement among modern humans to extract from, exploit the resources of, and dominate the natural world, which

they link to an early modernist conceptualisation[3] of humans as separated from nature. They are now trying to reconfigure the relationship between humans and nature as one of mutual co-constitution and interdependence rather than ontological opposition. Indeed, BIO STORIES stakeholders envision an ideal future as one of greater affinity in both human social relations and human/nonhuman ecological relations.

They insist that the achievability of such a future is premised upon the our willingness in the present to: (A) embrace different value systems that include reciprocity with and respect for the living world; (B) foreground the social ecological benefits of new biotechnologies beyond their usefulness from an economic perspective; and (C) prioritise inclusive approaches to innovation that are not solely orientated to instrumental applications of novel technologies at scale.[2]

These may seem challenging to actualise because the dominant mode of rationality and purpose guiding synthetic biology today remains largely utilitarian. Industrial orientations are sustained through a combination of strategies, including: (1) the commitment to make biology easier to engineer through the adoption of engineering principles; (2) the aspiration to make synthetic biology serve specific social goods; and (3) the demand of funding agencies that experimental results produce value in the commercial sector. That said, stakeholders whose perspectives are represented in BIO STORIES offer us language for beginning to realise this desired future, given the realities of the present.

ACKNOWLEDGING INTERDEPENDENCIES

What does ‘ecological’ mean in terms of the many forms in which it is envisioned by the diverse stakeholders of BIO STORIES? In one sense, embracing ‘ecological’ paradigms means devaluing industrial ‘economic equations’ as metrics for evaluating humanistic and ecological successes and failures. In another, adopting an ‘ecological’ perspective in synthetic biology is akin to applying whole-systems thinking to reframe human-nature

3. Wynter, S. (2003) ‘Unsettling the Coloniality of Being/Power/Truth/Freedom: Towards the Human, After Man, Its Overrepresentation–An Argument’, CR: The New Centennial Review, 3(3), 257–337. Available at: http://www.jstor.org/stable/41949874.

[2] These priorities emerged during thematic analysis, in which relationships were identified between passages of text affixed to the following code categories: Temporal Horizons, Relations and Values (see Codebook for descriptions of codes).

relations. Such an orientation enables stakeholders to recognise the interdependence, agency and inherent value of nonhuman others with which humans coexist and upon which our technologies have impact. In turn, this compels some stakeholders to reflect more critically upon the values steering their work.

Carole Collet: *We take nature for granted, but when you look at it, when you spend time observing, understanding the natural world, it's mind-boggling. You just think, how could that have evolved in this way? And of course we know from Darwin that it evolves to survive, and it's evolved to adapt, to be fit for purpose. And so in a way, that's what synthetic biology is trying to do: we adapt life so that it's fit for purpose. Yet with synthetic biology, we make it fit for human purpose. It's an egocentric and anthropocentric approach.*

Strikingly, perspectives such as these accentuate the need for humans to embrace humility and solidarity with respect to the rest of the living world. Whereas the World Economic Forum Global Futures Council frames humility as an approach to innovation that ought to temper hubris when making claims about synthetic biology's potential benefits,[4] in BIO STORIES, the value of humility acquires the status of an existential virtue. Many stakeholders, for example, find themselves profoundly humbled by the complexity and diversity of ecological and biological systems, insofar as these systems radically throw humans' self-understanding—as individuals and as a species—into question.

Maurizio Montalti: *We are all made of cells and most of these cells are not even human. The consortium of cells that live in and on us, that would be skin, throat, guts and so on, might be way more in control than the way we think we are in control. So somehow what I find interesting when thinking about the relationship between nature and culture, us and nature, us and biology, is the fact that this idea of singularity, of the individual, is completely overcome and overpassed by the idea of plurality, by the idea of being many. And the idea of being many means actually being in continuous relation with other agents that contribute to and define who you are and inform the way you act. So in the same way in which life acts on us, we constantly act on life itself.*

By ceding the pretense of human domination over nature, stakeholders reimagine themselves—with greater humility—as living beings who co-exist with

4. Molloy, J. (2021), Revisiting & Realizing the Promises of Synthetic Biology: Briefing Paper, council notes, World Economic Forum, Global Future Council of Synthetic Biology, delivered August 2021.

other living beings in a wider 'multispecies' ecology.[5] Moreover, by acknowledging humans' commitments to other species and shared ecosystems, stakeholders add critical nuance to the value of solidarity, expanding it into a more-than-human ethic.

Ionat Zurr: *We need to have real discussions about who is going to benefit from biotechnology. Maybe we can also begin to look at how our technologies not only benefit humans, but try to put 'the human' aside and look at how it's going to actually benefit other ecosystems.*

At the same time, envisioning an ecological future for synthetic biology is not solely a matter of rethinking human-nonhuman relationality; it is about community, writ large. Indeed, stakeholders also apply systems-thinking when articulating ways to strengthen human-human relations of affinity in the present.

Douwe Korting: *I'm one of the founders and a board member of the Herenboeren concept, which is changing the ownership of the food project from the business and the bank, to the consumers... The collateral benefit of this is not only the food, but it's the community, it's better soil, it's more biodiversity, it's more nature, it's a nature-driven way of producing. So just by sharing the farm, you create other benefits. So that's my goal for the future... Just by starting a new system, it's a mandate for getting a community in action.*

Strategies for increasing social solidarity are expressed in a variety of ways, ranging from more focused investments in local practices (e.g. farming, engineering, science), the need to restructure regulatory systems more equitably across national boundaries, to more inclusion of diverse perspectives when making decisions about how to advance the field.

Corinne Okada Takara: *How do we create new spaces? How do we create these spaces where academics and researchers and any person walking down the street in their community can come into a garden, a community garden or a parking lot and bring their knowledge to the table? ... I've learned so much in developing 'BioJam', which is anchored in Stanford Bioengineering, and what we're looking at is how do you create space for teens to come from low-resource communities, from agriculture communities, to share space with researchers who are in synthetic biology and co-develop programming, learn about synthetic biology. And then the teens take their learnings from that space back into the communities... It's really about the process of learning that creates a sense of belonging. It's about creating generative learning spaces where we can grow vocabulary together and elevate others.*

5. Rees, T. (2020) From The Anthropocene To The Microbiocene. Available at: https://www.noemamag.com/from-the-anthropocene-to-the-microbiocene/

A significant theme throughout these dialogues is the belief that consciously cultivating both natural and social environments or 'spaces' is necessary to ensure solidarity and increase equity, reducing alienation in the present and assuring greater affinity in the future.

Several stakeholders perceive a need to create new infrastructures that enable technological innovation and translation to be driven by context-specific needs as articulated by end users. The logic is that novel biotechnologies responding directly to local problems and demands will transition more smoothly from research to the commercial sector and link innovation to application.

Paul Freemont: *When you let the floor open and let people start thinking about the technology once they know basically what it is, the problems that they came up with that may be addressed by the technology were very local. You know, some real local problems. That's exactly what the technology needs because it's those local problems that pull the technology into [the] application space more quickly.*

Other stakeholders—namely artists, activists, designers and humanities scholars—flip the script by speculating whether desired futures may be more achievable if synthetic biology becomes less technology-driven and more curiosity-driven, instead of orientated primarily to 'problem-solving'.

Jahnavi Phalkey: *If we were to think about a living-systems laboratory that had some historians and some designers and some biologists working together, you already have a mix that would create interesting questions that go beyond problem-solving. I think what is happening now—from my experience working in universities in Europe, the United States and India—is that problem-solving and knowledge-making are almost pitted against each other as if they are antagonistic to each other. And that is highly problematic because once you've defined the 'problem', you've identified the plausibility of its ability to be fixed. The chance that you might pose new questions from a completely different place outside the problem is that much lesser.*

From this vantage point, the problem with synthetic biology's discourse being overly focused on problem-solving is threefold: (1) such utilitarian pragmatism orientates biological inquiry toward the immediate translation of new knowledge into technological applications, thereby delimiting which research questions are posed and thus what innovations are made possible; (2) problem-solving paradigms often

define complex problems univocally, obscuring differences of opinion on what 'the problem' actually is, whose perspectives are considered when defining demand, what solutions are most desirable and for whom; and (3) this seemingly practical orientation hinges implicitly on an assumption that problems can be solved with biotechnological applications. While the latter is very often true (as in the case of vaccines), it is also only ever partly true. Complex social and ecological problems do not go away once they are technologically 'solved'. Often, biotechnological fixes create other social and ecological problems that lead to further alienation.

Roel Bovenberg: *In the early days when people started to think about genetic modifications and useful applications, one of the ideas was technology-driven: if we just fortify rice and provide it with the genetic equipment to make the vitamin itself, this would solve a huge nutrition problem across the globe. This was the thinking behind Golden Rice, which started all sorts of debates about how desirable this was. What was the arrogance, so to say, of having this scientific solution developed and proposed to the largest community of people who have rice in their daily diets? And the irony I just learned is that it can now only be commercially bought as a sort of high-end product, only to be afforded by people who search the web for this particular product and can afford it. So starting with the idea to have a nutrition solution for the many, ending up here on the table for just a few.*

What all of these diverse perspectives share is an affective longing for other ways of relating to the living world and for practising reason, beyond those that are incentivised by consumer capitalist models of value and industrial models of control.

Selassie Atadika: *In terms of the future, I think it's about having respect for your soil, having respect for your climate and understanding what it does, rather than forcing it to do something it doesn't want to do.*

There is a hope that future biotechnological innovations and strategies will be pursued in line with social-ecological perspectives that foreground the interconnectedness and inherent value of the multiple entities that constitute and support the living world.

Chido Govera: *In this age of innovation, why is it that when I go back to the forest where I used to harvest thousands of mushrooms, the mushrooms are still disappearing? Because in trying to fix food systems, we are introducing things like artificial fertilisers, which are very innovative when they arrive, but somehow they lose this awareness of the long term relationship. When I become a mushroom farmer, I tend to just think about what I need only to preserve the mushroom that I know. I need only to continue*

with the awareness of mushrooms for food for humans, but not mushrooms in the ecosystem, in the form of something more, to understand the community, the ecosystem, to acknowledge the existence of the other.

Other interrelated values emerge from the dialogues, including: courage, curiosity, gratitude and respect for nature, human ingenuity, protection of the Earth, reverence for history, sharing and trust. Taken together, these values translate into an ethical understanding of human-nature relationality, which stakeholders perceive as integral to steering the field of synthetic biology towards its desired futures.

SEMANTIC SHIFTS

Analysis of the stakeholders' discourse, specifically their metaphors and figures of speech, provides a glimpse into new ways of thinking about and practising synthetic biology.

Synthetic biology began with an aim to apply rigorous engineering principles to the design and development of biological systems.[6] In this context, mechanical metaphors emerged—'chassis', 'parts', 'devices', 'tools', 'factories', 'building blocks of life', etc.—and were adjoined by computing analogies—'operating systems', 'circuits', 'programmable microbes', organisms as 'machines', cells as 'hardware', genes as 'software', etc.—to represent the inner workings of synthetic biology.[7]

Today, however, there is widespread agreement among diverse stakeholders that these conceptual metaphors ought to be rethought because they reinforce an idea of biology as being little more than material resources to be exploited by humans.

David Sun Kong: *From a synthetic biology or an engineering perspective, you view the object as this engineering substrate, which to me is something we need to challenge and interrogate. When the cell is a factory that is supposed to produce molecules for humans, it ends up being this question of 'What can this organism do for me?' 'What is the way that I can exploit this organism to get it to give something beneficial to me?'*

6. Void, C. A. (2012) 'Synthetic Biology', ACS Synth. Biol., 1 (1), pp. 1–2.
7. Balmer, A.S. and Herreman, C. (2009) 'Craig Venter and the Re-programming of Life: How metaphors shape and perform ethical discourses in the media presentation of synthetic biology', in Nerlich, B., Elliott, R. and Larson, B. (ed.) Communicating biological sciences: ethical and metaphorical dimensions. London: Ashgate, pp. 219-234.

Interestingly, stakeholders no longer take the use of engineering analogies for granted as neutral descriptors of synthetic biology. This is not to say that engineering idioms for describing natural technology are suddenly and unanimously considered 'bad'. Nearly all participants acknowledge that metaphors can both conceptually open up and foreclose ways of thinking, doing and communicating synthetic biology.

Natalie Kuldell: *You mentioned the metaphor of Legos and the idea that we can snap together these little snippets of DNA and have a genetic programme that might run in a reliable fashion. I think that that is a goal, a desire. It's built on certain principles from other engineering disciplines that have been successful and are more established. The notion of standardisation of parts in order to enable greater diversity of built outcomes... I think it's counterintuitive and so, in that sense, a wonderful teaching point, the idea that if you standardise components, then suddenly you actually expand the range of possibilities rather than narrow them... But for sure, any metaphor has its limits. I think that's why we need many.*

Some are actively searching for new metaphors to represent their relationships with nature along the lines of ecologically imbued values. Some, for example, eschew mechanical analogies—like 'building'—in favour of organic metaphors—like 'growing'.

IZ: *When teaching, it's very important for me to always remind the students, yes, we're changing things, but we're not building things. We're working with materials that were built already. And also those materials are in process, those materials are changing... They're not like a Lego. They are actually growing things. And we need to really, really be aware of that understanding of the materials and to understand how different they are from the way engineers may look at them.*

Craftsmanship metaphors—such as 'carving', 'fabricating' and 'sculpting'—appear in these dialogues to describe processes of working with organisms in an instrumental yet humble manner that privileges deep relationships with biology over mastery of technique.

COT: *You're studying the surfaces of a radish and how the carving will flow with it. It's really being creative with biology; you're working with its contours and the material texture. And you learn what's too deep a cut and what's just the right surface and you're playing with that outer red surface; when you carve it away there's some of the white. So, what are the properties of the organism that you are working with?... It's a meditative experience working with carving a radish in this way. Yes, so the experience, the process, I think, is part of the journey.*

‘Bio-facturing’ and ‘bio-welding’ are other craft idioms invoked to figuratively ontologise biological processes as, themselves, manifestations of craft.

MM: *The cells fuse with each other as in, what one could describe as, ‘bio-welding’.*

Again, these sorts of discursive displacement portend an ethical reorientation, primarily one of humility and solidarity, in relation to the agency of nonhuman life forms with which one works and to which one ought to carefully listen.

Natsai Audrey Chieza: *I spent about a year trying to figure out how to ferment the organism so that it would produce its beautiful pigment, with a non-scientific background, and reached a dead end effectively. And I realised upon evaluating a year’s worth of research in the lab that maybe I was approaching this in a slightly wrong way, that perhaps the thing I needed to do was not show the organism what I wanted it to do, but to understand how this organism lives and lives well, and how I could integrate that into my design process. And it was only at that point that I started to grow the bacteria directly onto the textile in a process that we referred to as solid-state fermentation. And when that happened, this organism was able to deploy, in a very direct and precise way, pigment molecules directly onto the textile. Suddenly the process was colourfast.*

Several stakeholders describe ‘partnering with nature’ and ‘respecting our partners’ by treating them less as ‘living materials’ and more as ‘microbial actors’ with whom they ‘collaborate’.

JR: *We don’t want to repeat the same mistakes that we had been making already in the industrial paradigm. We want to start working with nature instead of against nature. We want to engineer and partner with nature and biological organisms instead of just dominating them or mastering them or trying to deploy them only for human ends because I think doing that has brought us a lot of problems as well. So how can we shape the language with other words? For instance, partnering with organisms or working with actors or seeing them as partners or agents instead of seeing them as machines or little factories even.*

In general, contemporary stakeholders identify an antithesis between mechanical and organic metaphors insofar as they provide particular interpretations of synthetic biology. There are at least two ways to interpret their semantic shifts. On the one hand, some stakeholders feel ideologically compelled to seek new metaphors beyond those issuing from engineering disciplines. They assimilate organic as well as metaphysical images into the semantic field with the

hope that new ways of speaking may precipitate new ways of doing. When semantic shifts are more theory-driven than practice-driven, however, stakeholders ironically end up orientating to reality as something to be engineered through speech. Implicit in this perspective is the idea that language influences reality and can thus proactively reshape cultural values, rather than merely reflect them post factum.[8]

On the other hand, there are some stakeholders for whom old metaphors do not capture the processes with which they presently engage. For them, the use of new idioms reflects their particular ways of working and interacting with biology; their semantic shifts represent their already shifting practices. In either case, these discursive practices create new meaning around working in/with biology today.

MODALITIES OF PRACTICE

Drawing from personal experience and their own professional practices, the speakers across these dialogues collectively rethink relations between bios and anthropos in the interest of imagining ideal possible futures. From this diverse set of stakeholder voices, we have distilled several core figures – 'ideal types'[9] – that aid our grasp of the perspectives on nature most consistently appealed to. Taken together, our core figures or 'types' of human actors schematise the different available approaches to nature, the tropes each relies upon and the values each expresses. Each figure offers different insights into how we may begin to actualise desired futures today.

The Farmer's Practice

The farmer who tends to nature knows what to harvest, what to sow, what to slaughter. Some consider the farmer's agricultural praxis a science, others consider it an art. Some see it as traditional, others view it as cutting-edge, insofar as the farmer's knowledge of breeding has recently become translatable and seen as valuable for genetically engineering food products. Farmers can use high

8. Science Direct (2022) Sapir-Whorf Hypothesis Overview. Available at: https://www.sciencedirect.com/topics/psychology/sapir-whorf-hypothesis.
9. Weber, M. (1949) 'Objectivity in social science and social policy', in Weber, M., Shils, E. and Finch, H. A., The Methodology of the Social Sciences. Glencoe [Illinois] : Free Press, pp. 49-112.

and/or low technology to optimise their crops yields, but the most important technology they work with is nature itself. The farmer understands that nature is a technology for growing food. The farmer, in their place, harvests what nature grows and ingeniously uses natural technologies, such as composting, to produce ecological and economic value: better soil health and higher crop yields. The farmer works with and tends to nature so that nature may do its work.

Through working directly and intimately with nature, the farmer comes to understand its rhythms while respecting its constraints. That said, farmers in an industrial agricultural context are far more constrained than those in a cooperative community context. Smaller-scale farmers are capable of laying the foundation for a sustainable food system, while industrial farmers are often captive to economic incentives that alter their relationship to nature, such as being required to buy genetically modified seeds instead of native germplasm or to use pesticides and herbicides when growing vegetables to sell to the market.

The farmer embodies the values of solidarity and social cohesion, ecological humility and industriousness. The practical wisdom they impart is that outpacing or outperforming what nature provides will inevitably lead to problems.

DSK: *Each farmer that visits our farm says: 'Well, it's a nice system, but you can't feed the world'. There isn't any farmer who feeds the world on his own ... it's not the intention that we feed the world. But my farm is feeding 75–80% of my stomach and my wife's and my children's and all the other members. So it's not an issue that you have to feed the world.*

The Engineering Scientist's Practice

The scientist wants to understand and to generate knowledge of the living world. Unlike the farmer, scientists do not restrict themselves to managing natural materials; in synthetic biology fields, they also invent new ones. Their practices are tethered to a history of modern knowledge production, which includes ideologies of mastery and control along with subservience to the institutional (economic and political) demands of the day. Trained to revere objectivity, they embody the notion of being on the outside of nature looking in. At the same time, they increasingly understand that scientific praxis and

technological innovation cannot be, and has never been, separated from value judgments. Indeed, the scientist is increasingly sensitive to the fact that their pursuit of scientific knowledge always raises social and political questions, that their research agendas are always taken up in cultural contexts, that there is a difference between truth and meaning, that they can pursue objective truth seeking while advocating moral objectives, and that matters of fact are often laden with questions of which values matter.

Although the scientist has to reckon with mounting public distrust of their aspirations and claims, they are nonetheless committed to pursuing research questions and potential applications in the service of humanity. The scientist embodies the values of ingenuity, humility, responsibility and industriousness. The practical wisdom they impart is that rebuilding trust, staying humble and remaining open to learning new things, especially outside of conventional comfort zones, is integral for ensuring that future scientific knowledge-making serves our species, our societies and our ecologies. This includes dialoguing with the wider public while advocating honesty so that society gains the necessary understanding of their work and politicians are enabled to make optimal decisions.

Kyle Lauersen: *I think it's our job as scientists to show what's possible and to be as engaged with the public as possible, to say: 'Hey, look, this is what we can do. This is what it's possible to do. This is what nature has given us and how we can use it.' And to say nature isn't perfect. We're not perfect, but we can actually apply design principles now to natural systems to try and make them better... I think we have to learn to be shepherds of the planet. We have to engage with nature at its level and understand it and also learn from it.*

The Grand/Mother's Practice

The Grand/Mother not only nurtures her kin, but respects them; she allows her relatives to be as they are and become as they may. She parents with courage not control; that is, she lets her wards explore, play and experiment on their terms. The Grand/Mother is akin to the cell culture incubator found in nearly all modern life science laboratories: humble and seemingly insignificant from an aesthetic point of view, yet necessary for sustaining life. The knowledge she generates and imparts, however, is not confined to the laboratory, but makes a laboratory of the world. Like the scientist, her knowledge of the

living world comes from a process of interaction and contextual familiarity. Unlike the scientist, however, the grand/mother does not try to control nature in order to understand or improve it.

Gillian Marcelle: *Your grandmother was able to provide you with knowledge about natural phenomena, to convey information about processing, to convey information about different uses, to identify varieties, to provide you with information about those natural materials in context, which means that not only was she a scientist, she was displaying the best of scientific method because you also said that she was able to convey that information in a way where you could replicate it.*

The grand/mother is not typically presented as the face of 'science', per se, but she is increasingly viewed as an integral science communicator. The information she passes on provides us with the rules of inquiry and the contents of innovation. Moreover, her attentiveness cedes us the necessary conditions for pursuing both, for she fabricates spaces safe enough for her relatives to dare to try, to fail, to correct mistakes and to learn.

The grand/mother embodies the values of empathy, gratitude, humility, respect and courage. The practical wisdom she imparts is that it is not possible to eliminate things beyond our control, even things that may harm us, and that we ought instead to develop ways of nimbly addressing problems when they do arise.

Drew Endy: *One of the things I love about my mum is when I was growing up she let us be children. She didn't control what we were doing. Now that I'm a parent I find this amazing and terrifying. Like, how was she a parent in this way, because I'd have a bow and arrow in the yard? I'd just shoot it straight up in the sky. We could do all sorts of things that are terrifying and lucky to be here, but, as a parent, one of the things I respect and love about her is that she didn't control me... I don't wish for a future in which I absolutely can control biotechnology. I wish for a future in which I'm a good parent and we're good parents to our creations.*

The Artist's Practice

The artist shares residence with laboratory scientists and plays a complementary role in innovation and creation by asking different questions. Like scientists, artists in synthetic biology conduct experiments, albeit often for different reasons; they use the same tools, albeit often for different ends. Because their creations are driven more by curiosity, fascination and inquiry

than by incentives to solve problems, the artist is quintessentially disruptive. Their path proceeds along a series of disorientations and detours that compel science to account for itself. Artists' sensibilities and insights are instrumental in the early stages of conceptualising and designing research projects, not just in illustrating or analysing their impacts further downstream. Like the grand/mother, the artist is a storyteller and an educator who offers visual and conceptual language for bridging communities.

The artist works with nature in a way that foregrounds careful attention to embodied craft and to creative acts that are worthy of attention beyond what is considered valuable by institutional (state-owned, corporate, academic) gatekeepers. They embody the values of tact, ingenuity, multiplicity and complexity. The practical wisdom they impart is to embrace chance and process as method.

IZ: *I'm an artist working with biology and biotechnology as a medium for artistic expression. I started probably in the mid '90s, working with tissue engineering and regenerative biology... I started a laboratory within a scientific department that is dedicated for artists to work with biology, but to do research for more cultural philosophical questions rather than science. And we also have actual scientists coming and doing research with us, research that they could not have done within their scientific career.*

The Curator's Practice

The Curator travels with and serves as a mediator between all of the figures above. They bring people together by 'representing' stories to a wider world, engaging with publics and communities, producing events and even creating experimental social situations. In the name of design, they connect disparate knowledge, sensibilities and insights, providing these and the staged relations between them as resources for further thought.

This mode of translation affords the curator a somewhat privileged position, one which they occupy with care (the term curator comes from the Latin curare, meaning to take care, cure or help, rather than door-keeping). In the context of BIO STORIES, the curator operates as a relational barometer of an expanded and expanding field of synthetic biology practices. To curate is to be attentive to this expansion, while recursively participating in it.

CONCLUSION

Contemporary stakeholders are rethinking the relations between humans, technology and nature as one of integration and mutual co-constitution rather than separation. This reframing invariably foregrounds ethical and political questions regarding how to encounter, intervene into and innovate the living world without further destroying and/or devaluing it. How should different cultural understandings of human-nature interdependence be integrated into the field's future goals? What are the responsibilities of fellow synthetic biology stakeholders to communicate and put into practice the field's desired relations, especially when their actualisation requires contending with broader structural limitations that extend beyond the synthetic biology fields alone? These are just a few of the questions that the BIO STORIES stakeholders invite us to consider.

Of course, there are other questions as well. For example, to achieve desired futures, how much socio-ecological solidarity will we actually commit to, at what costs and at what scale(s)? Will we be willing to scale out synthetic biology if it means sharing control over decision-making, innovating new interoperable technologies connecting other systems regardless of who owns those systems, pursuing equity and sustainability—at the risk of shrinking the global economy? How humble are we really willing to become?

The perspectives in BIO STORIES are diverse and their stories represent a multiplicity of ideas, all of which are open to different interpretations. This synthesis is one such interpretation that seeks to demonstrate how their perspectives, when taken together, provide us with the contours of new languages and ways of thinking, which may guide us towards desirable futures. BIO STORIES provides us with a nuanced set of values and considerations for envisioning the future. The challenge now is to think seriously and critically about how to fill these visions in.

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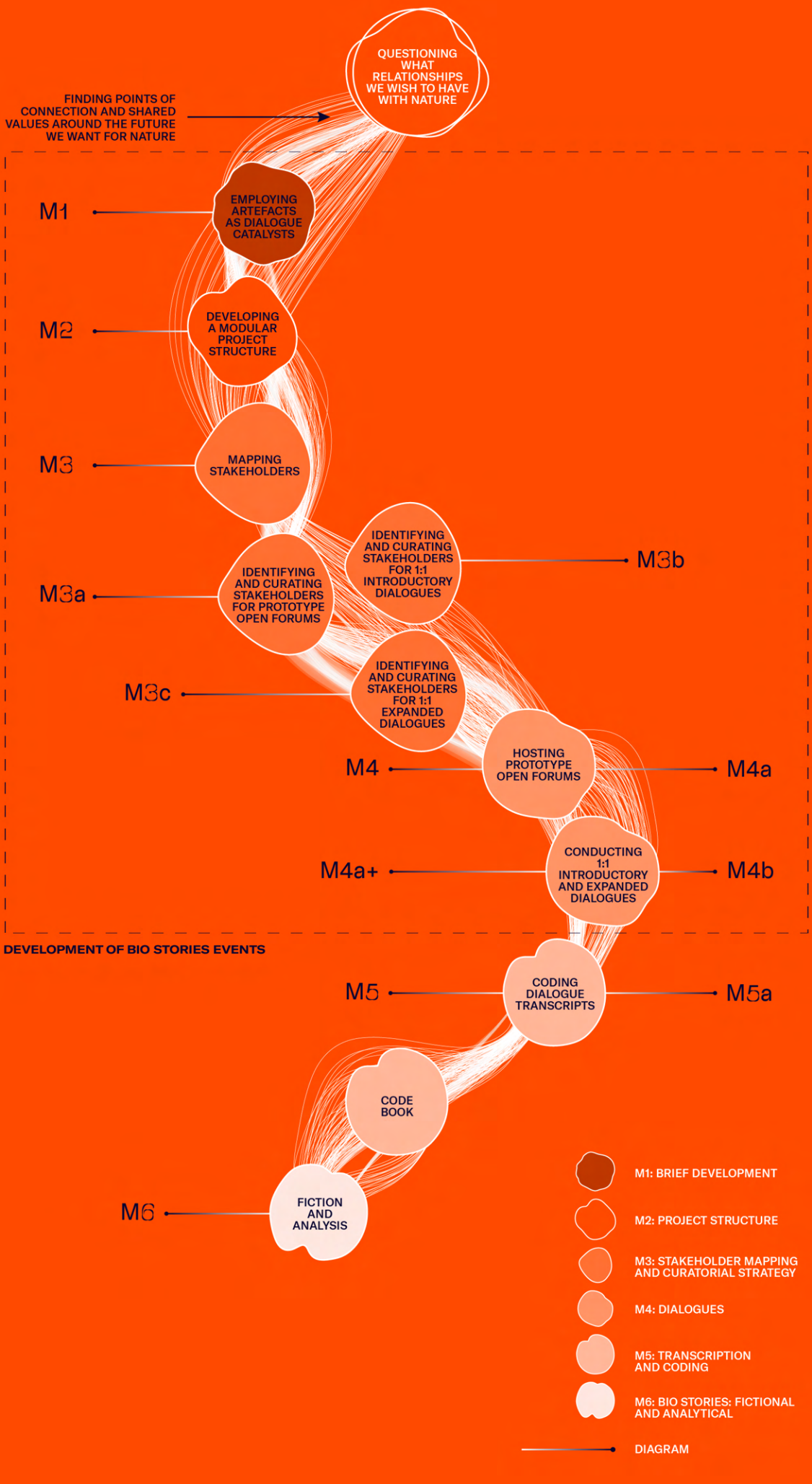
METHOD

BIO STORIES has been developed to create a space for storytelling in the field of synthetic biology. The project is designed to trigger moments of collaborative engagement around how and why we design with the building blocks of nature. Here, we make our method transparent and open, inviting others to replicate this strategy across multiple contexts and continue to grow BIO STORIES.

METHOD COMPASS



METHOD **M1: BRIEF DEVELOPMENT**

As synthetic biology co-evolves with cultural, economic and political domains—which continually affect and are affected by nature—how do we understand and share our experience of this emerging discipline in light of its transformative effects?

For millennia, people have come together to make sense of the world through shared stories. The act of storytelling is an intrinsically cross-cultural practice that fosters connectedness and underpins social integrity. However, current narratives around synthetic biology often default to ideas of commercial interest, techno-social imperialism or technocratic utopianism. This contributes to the ongoing concentration of thought leadership, access to technologies and the sharing of benefits in the global North, thereby limiting the transformative potential of synthetic biology.

The goal of BIO STORIES is to collect and curate narratives that clarify what is at stake through the ways in which we advance synthetic biology. Drawing on the understanding that: 'the stories we tell can either reflect the society we are part of, or transform it.'[1] BIO STORIES engages plural perspectives to contribute to and create new narratives about the development of synthetic biology, in the hope that these lateral visions will help positively influence the evolution of this transformative technology.

BIO STORIES has been designed to identify emerging narratives that coalesce around specific artefacts. Grounded in personal experiences, these objects are complex material manifestations of lived relationships with nature that also embody a distinct biological or biotechnological future. Using material artefacts as conversation prompts ensures BIO STORIES is accessible across all levels of expertise and disciplinary understanding, and invites the widest possible range of perspectives to contribute to the process. When used by participants as a means of introducing themselves and their personal and professional relationships with nature, artefacts from daily experience serve as points of departure for thoughtful and considerate lines of enquiry. These living narratives provide stimuli for observations and speculations that in turn form a bridge back to synthetic biology's real-time, real-life implications and impacts.

1. Brown, A.M. and Imarisha, W. (ed.) (2015) Octavia's Brood. Oakland, California: Ak Press, pp. 279.

METHOD **M1: REFLECTIONS**

- How do we establish which stories are told and shared?
- How do we expand the pool of individuals who get to tell and listen to these stories?
- In what ways do artefacts embody culture?
- How does the presence of an artefact influence the way we interact with each other?

METHOD **M2: PROJECT STRUCTURE**

The ways in which we come together in dialogue shape the stories that can be told and the insights that can emerge. In order to solicit complex and plural narratives[2] about synthetic biology, BIO STORIES rejects the deterministic one-size-fits-all approach associated with conventional focus groups and the Design Method.[3,4]

Instead, the project focuses on modularity as a means to replicate, expand and iterate the process in response to diverse contexts. As such, BIO STORIES is designed as an experimental process grounded in observation, with both the stories and methodology developed through active listening[5,6] to what is said, rather than looking for evidence to support a preformed hypothesis. The development process is transparent and accessible to the participants throughout and incorporates deliberate moments for feedback and reflection.

The project was structured in three parts: a prototype at Dutch Design Week 2021; an introductory set of three pilot one-to-one dialogues; and finally an expanded set of six one-to-one conversations.

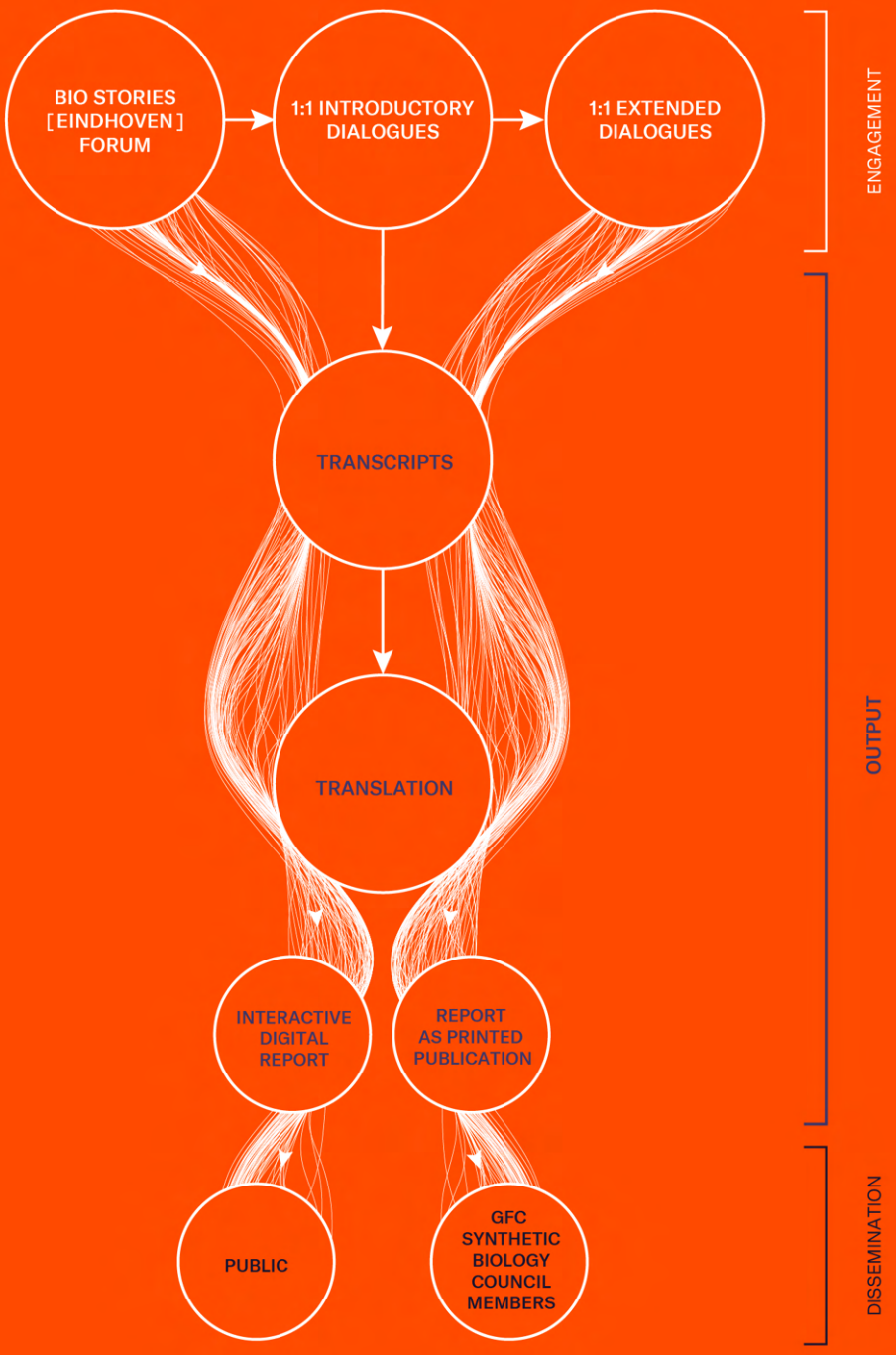
The prototype leveraged the convening effect of Dutch Design Week to bridge professional silos and refine the language and strategy of the project, in conjunction with diverse audiences, in an open forum. In order to stimulate dialogue about existing relationships with nature, rooted in the local context, Faber Futures designed a convening space that encouraged invited stakeholders and participating audiences to each bring their own seat to the table, while passers-by were welcomed in by a flag. Reclaimed from the nation-state narrative, the flag represented the hidden networks of interdependency that define nature. The in-person nature of BIO STORIES disrupted the spatial hierarchies typically associated with public synthetic biology events.

2. Escobar, A. (2018) Design for the Pluriverse. Durham and London: Duke University Press.
3. Ansari, A. (2016) 'Politics & Method', Modes of Criticism, Issue 2: Critique of Method. Available at: http://modesofcriticism.org/politics-method/.Escobar, A. (2018) Design for the Pluriverse. Durham and London: Duke University Press.
4. Costanza-Chock, S. (2020) Design Justice: Community-led Practices to Build the Worlds We Need. Cambridge, Massachusetts: MIT Press.
5. Pais, A.P. and Strauss, C.F. (ed.) (2016) Slow Reader: A Resource for Design Thinking and Practice. Amsterdam: Valiz.
6. Dumit, J. (2014) 'Writing the Implosion: Teaching the World One Thing at a Time', Cultural Anthropology 29, no. 2: 344-362. Available at: https://doi.org/10.14506/ca29.2.09.

BIO STORIES can be redeployed in different contexts to see what else might emerge when we gather to share our stories.

The introductory and expanded stages of BIO STORIES used a virtual one-to-one format as a way to facilitate dialogues beyond geographical constraints and pandemic limitations. The facilitation was refined to allow conversations to be generative and let the dialogue be guided by three artefacts: one nominated by each of the participants and one curated by Faber Futures.

For the expanded dialogues, the design team organised pre-meetings to allow participants to discover common ground prior to the conversation and eliminated the Faber Futures-curated artefact in order to put more of a focus on the stakeholders' own. Two carefully devised questions prompted the participants to reflect on their relationships with nature and biotechnology.



METHOD **M2: REFLECTIONS**

- How might further iterations of BIO STORIES amplify the project's democratic and plural nature? What obstacles are there?
- What should the next iteration of BIO STORIES look like? In what context should it be hosted and what might that bring to the process?
- What global-scale learnings can and should emerge from local, contextual observations? How can the stories feed back into their local context?

METHOD **M3: STAKEHOLDER MAPPING AND CURATORIAL STRATEGY**

BIO STORIES' curatorial strategy began with a stakeholder analysis. The framework that this generated enabled the creation of visual representations of the network of agents who contribute to and are impacted by synthetic biology.

Conventional stakeholder groups are commonly described using market-orientated terminology[7] that reinforces existing power dynamics. BIO STORIES expanded and diversified the stakeholder group through the inclusion of both the creative sector and the general public, incorporating voices from those active in the synthetic biology field and those impacted by it. The enquiry thus reached beyond the conventional techno-scientific and market-focused mode of exploration, examining technology as an integrated system, as opposed to a series of discrete products.

A non-hierarchical, diagrammatic map served as a selection guide. The intention was to avoid the internal bias effect, and to start from a place of conscious humility. A long list of potential stakeholders was compiled from recommendations provided by GFC members and the Faber Futures team. The nominations ranged across a spectrum of expertise and geographical location.

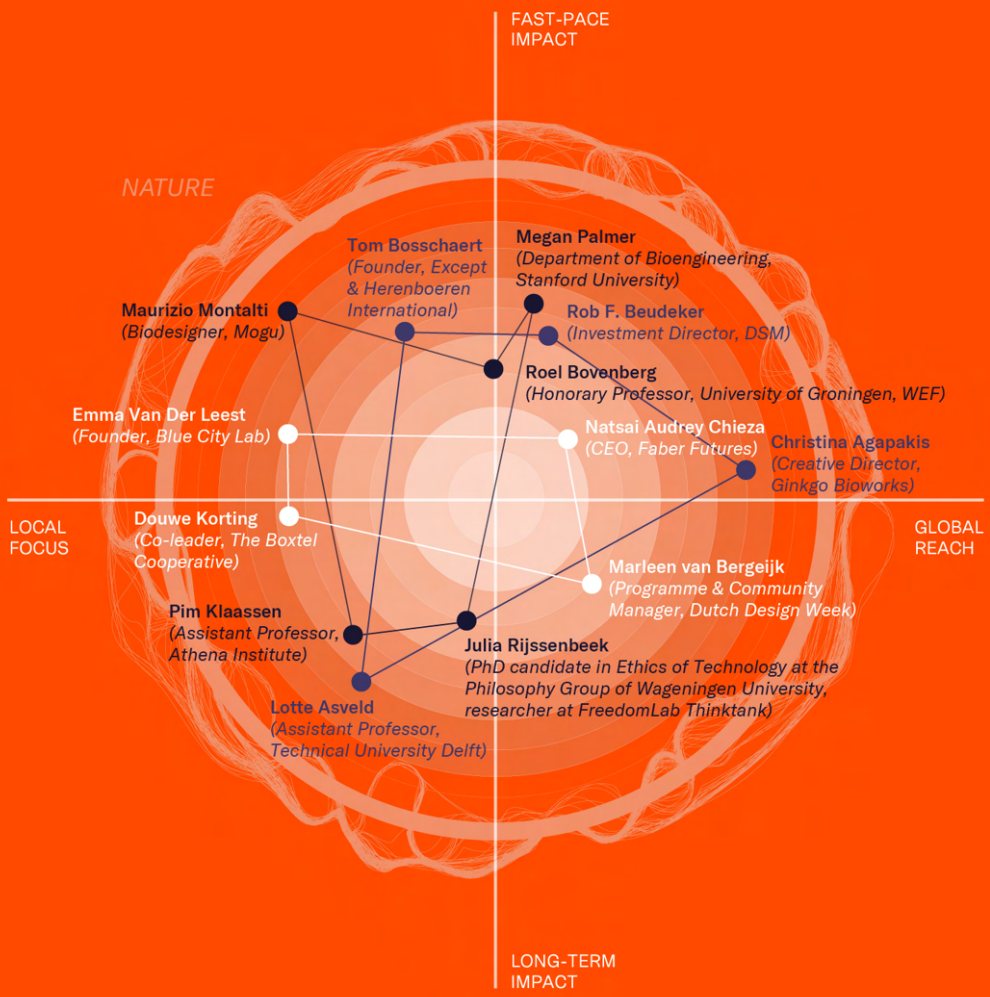
↓
STAKEHOLDERS

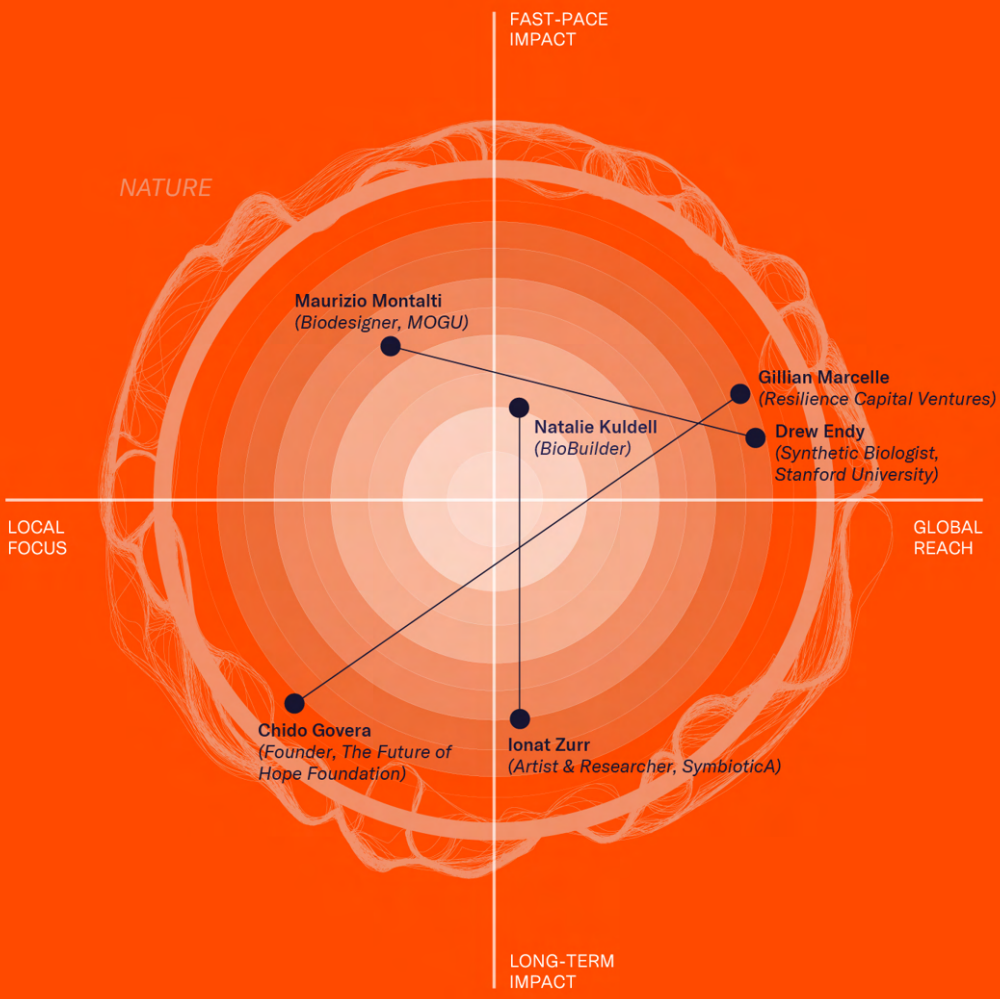
BIO STORIES' curatorial strategy for dialogue pairings worked across a set of axes that recognised degrees of visibility and influence (local to global), as well as different time horizons (immediate to long-term) in working with nature via synthetic biology, without imposing any hierarchies. The axes drew from Stewart Brand's Pace Layering theory,[8] which views a system's infrastructure as a group of dynamic layers that, in a healthy society, balance each other out. Similarly, Kate Raworth's concept of the 'doughnut economy',[9] in which planetary and social boundaries are complementary, informed the construction of the curatorial framework.

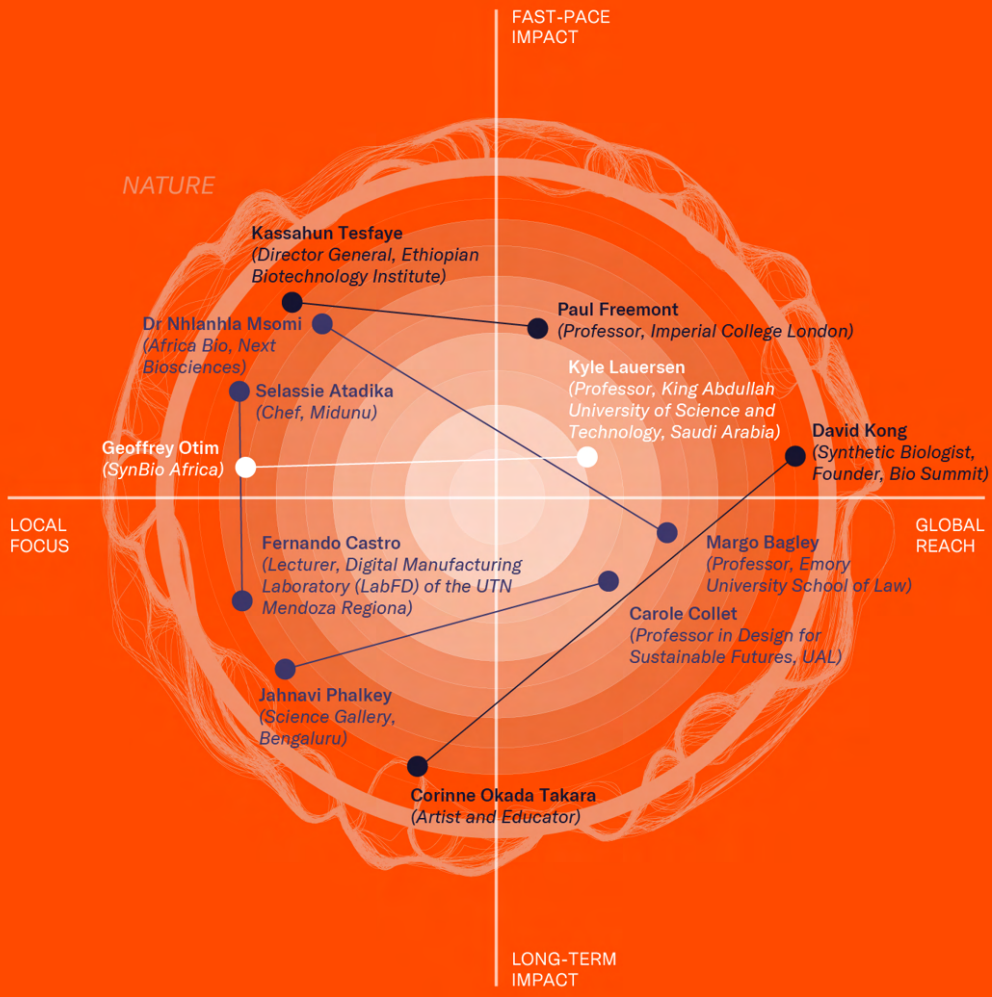
Once positioned on the map, the pairings were made across the axes to bring together stakeholders that shared common ground, but also demonstrated complementary modes of practice. This approach allowed for a systemic perspective on the complex, dynamic relationships that stakeholders have with nature.

7. UK Synthetic Biology Roadmap Coordination Group (2012) A Synthetic Biology Roadmap for the UK. Available at: https://openaccess.city.ac.uk/id/eprint/16096/1/Roadmap_SyntheticBiology_nrfinal2.pdf.
8. Brand, S. (2018) 'Pace Layering: How Complex Systems Learn and Keep Learning', Journal of Design and Science, Issue 3. DOI: https://doi.org/10.21428/7f2e5f08.
9. Raworth, K. (2018) Doughnut Economics: seven ways to think like a 21stcentury economist. London: RH Business Books.


NATURE
GOVERNMENT
Regional Governance
Regulators
Local Governance
International Organisations
Policy Advisors
CULTURAL INSTITUTIONS
Museums
Art Galleries
Publishers
Archives
Libraries
ACADEMIA
Academic Leadership
Students
Educators
Researchers
GRASROOT
Citizens
Activists
Community Organisers
INDUSTRY
Industry Associations
Companies
Think-tanks
Entrepreneurs
Investors
CIVIL ORGANISATION
Trade Unions
Social Enterprises
NGOs
Charities


FAST-PACE
IMPACT
NATURE
Tom Bosschaert
(Founder, Except & Herenboeren International)
Megan Palmer
(Department of Bioengineering, Stanford University)
Maurizio Montalti
(Biodesigner, Mogu)
Rob F. Beudeker
(Investment Director, DSM)
Roel Bovenberg
(Honorary Professor, University of Groningen, WEF)
Emma Van Der Leest
(Founder, Blue City Lab)
Natsai Audrey Chieza
(CEO, Faber Futures)
Christina Agapakis
(Creative Director, Ginkgo Bioworks)
LOCAL
FOCUS
GLOBAL
REACH
Douwe Korting
(Co-leader, The Boxtel Cooperative)
Marleen van Bergeijk
(Programme & Community Manager, Dutch Design Week)
Pim Klaassen
(Assistant Professor, Athena Institute)
Julia Rijssenbeek
(PhD candidate in Ethics of Technology at the Philosophy Group of Wageningen University, researcher at FreedomLab Thinktank)
Lotte Asveld
(Assistant Professor, Technical University Delft)
LONG-TERM
IMPACT


FAST-PACE
IMPACT
NATURE
Maurizio Montalti
(Biodesigner, MOGU)
Gillian Marcelle
(Resilience Capital Ventures)
Natalie Kuldell
(BioBuilder)
Drew Endy
(Synthetic Biologist,
Stanford University)
LOCAL
FOCUS
GLOBAL
REACH
Chido Govera
(Founder, The Future of
Hope Foundation)
Ionat Zurr
(Artist & Researcher, SymbioticA)
LONG-TERM
IMPACT



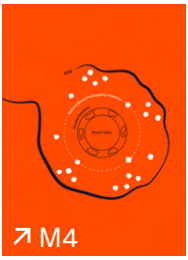
METHOD **M3: REFLECTIONS**

- What stakeholders were not represented in the past iterations of BIO STORIES and why?
- What role did the internal biases of the design team play in the curation of the project? How was decision-making impacted and what kind of hierarchies were established?
- How can the curatorial process become more distributed to further expand the perspectives represented?

METHOD **M4: DIALOGUES**

BIO STORIES creates space for people to come together in dialogues based on two foundational pillars: storytelling and active listening. Recognising that no two interactions are the same, external facilitation is responsive, yet purposefully limited. Through this process, participants are empowered to share their stories in response to selected artefacts and their own personal experience.

The BIO STORIES prototype engaged the community local to Dutch Design Week Eindhoven in order to collectively explore how synthetic biology might reframe our relationships with nature. To solicit local insights on a subject that non-experts might feel removed from, the space was designed to be comfortable and to encourage active participation. Upon entering, both panellists and audience members were invited to pick up a stool and bring their own seat to the table. The levelling of the hierarchy shifted panellists' expectations and allowed them to speak from beyond their professional modality. It also empowered audience members to participate in the conversation, drawing from the artefacts on the table and sharing their fears, hopes and questions with the panellists.


↗ M4

Over the course of the three-day forum, a number of audience members returned to follow emerging themes that were meaningful to them in order to go deeper in their questioning. Responding to the shifting dynamics in the room, the Faber Futures design team refined their facilitation by asking more inviting, personal and direct questions and holding space for silence to give time for thinking and processing.


↗ M4a


↗ M4a+

Building up from the local focus of the prototype, the Introductory and Expanded Dialogues engaged stakeholders from across the globe, bridging between contexts and across professional silos. During the one-to-one dialogues, external facilitation was minimised to provide space for the participants to make their conversations their own. Before each conversation, the design team provided leading questions, which focused on the expertise and shared interests of the two participants. Artefact-based introductions began the conversation, allowing the participants to ease their way into expansive, fruitful exchanges unhampered by

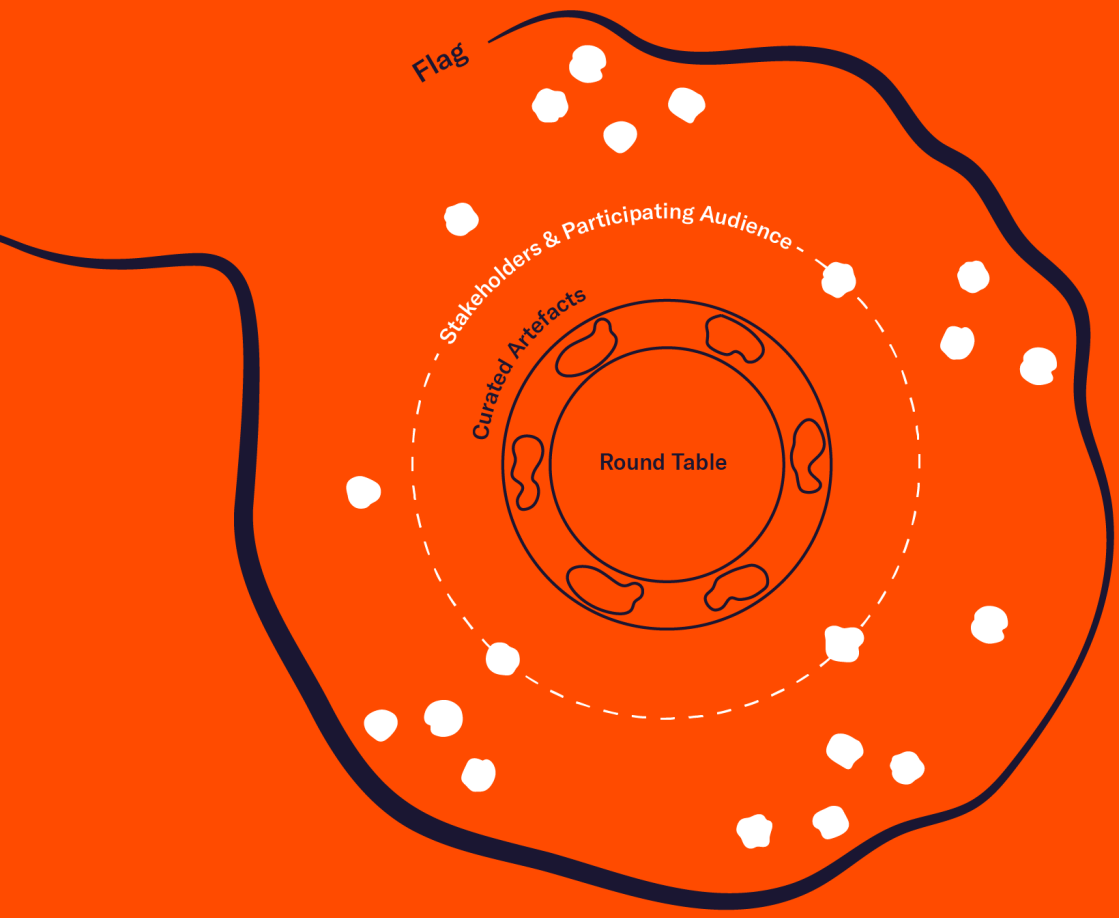
↗ M4b

technical issues, language barriers or professional blind spots.

Despite thoughtful planning and scaffolding prior to the dialogue, conversational dynamics shifted depending on the personalities, backgrounds and dispositions of the participants. Some pairs journeyed together and connected around unexpected questions and stories, whereas other conversations reflected some of the power imbalances of the Western-centric status quo. BIO STORIES asks us to recognise this and listen not only to which stories are told, but also to how they are told and what is left unsaid.

M4

SPATIAL SET UP: OPEN FORUMS



PARTICIPANTS OVERVIEW: BIO STORIES [EINDHOVEN]

Roel Bovenberg
(Honorary Professor, University of Groningen, WEF)

Maurizio Montalti
(Biodesigner, Mogu)

Pim Klaassen
(Assistant Professor, Athena Institute)

Rob F. Beudeker
(Investment Director, DSM)

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Megan Palmer
California, USA
(Department of Bioengineering, Stanford University)

Christina Agapakis
Boston, USA
(Creative Director, Ginkgo Bioworks)

M4a+

PARTICIPANTS OVERVIEW: 1:1 DIALOGUES

M4b

DIGITAL SET UP: 1:1 DIALOGUES

METHOD **M4: REFLECTIONS**

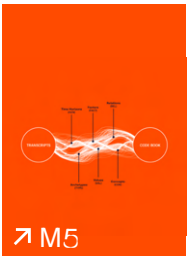
- What kinds of relationships can emerge between those who come together in dialogue?
- To what extent is facilitation required to mitigate against power dynamics that replicate histories of dominance and exclusion?
- What impact does an institutional context have on the conversations that happen within it?

METHOD **M5: TRANSCRIPTION AND CODING**

Coming together in dialogue can enable us to dissolve our implicit assumptions and create space for a shared narrative to take shape. In a similar way, BIO STORIES emerge from these transcribed dialogues through a non-conventional anthropological inquiry that considers the plural ways of thinking, knowing and doing synthetic biology articulated by the stakeholders.

BIO STORIES leans into anthropology, the study of the human figure, to analyse the practices, discourses and strategies that illustrate what is at stake in the ways synthetic biology is advanced. Anthropological inquiry is ordinarily encounter-based and relational, situating any findings in place and time. For this project, rather than conducting fieldwork, the anthropologist worked within a grounded theory framework, applying coding techniques to the dialogue transcripts in a form of qualitative analysis.

Coding refers to the process of assigning labels to data segments, thereby enabling a manageable analysis of the transcripts, as well as facilitating the identification of common threads running across them. Rigorous and systematic, this methodology does not aim to prove any pre-existing theory, but instead allows for the emergence of ‘theories’ or stories of human-nature relationships that are grounded in the data itself: the stakeholders’ descriptions of their practices, their judgments about the present and their orientations to the future.


↗ M5

The development of a codebook and the coding of the transcripts was an iterative process.
On each read, new tags were added into the codebook, which functioned as an instruction manual on when and how to apply codes to transcripts. Once the codebook structure had been refined, all codes were re-applied across the transcript set and relationships between categories of codes were explored. This enabled the team to trace interesting storylines across the aggregated data, allowing for grounded BIO STORIES to emerge.

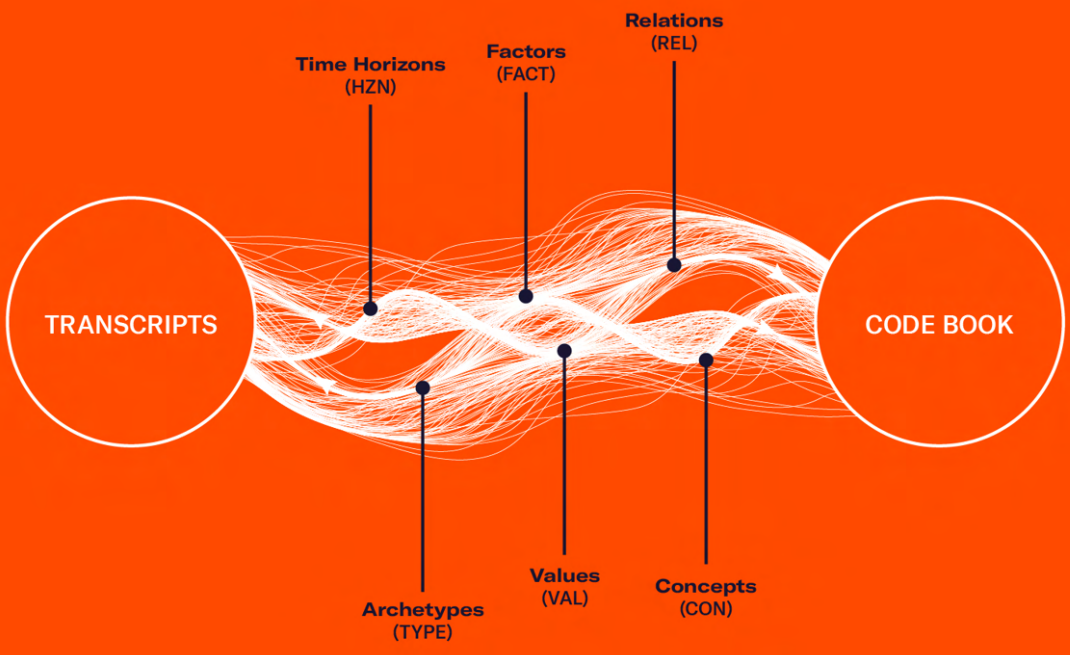

↗ M5a

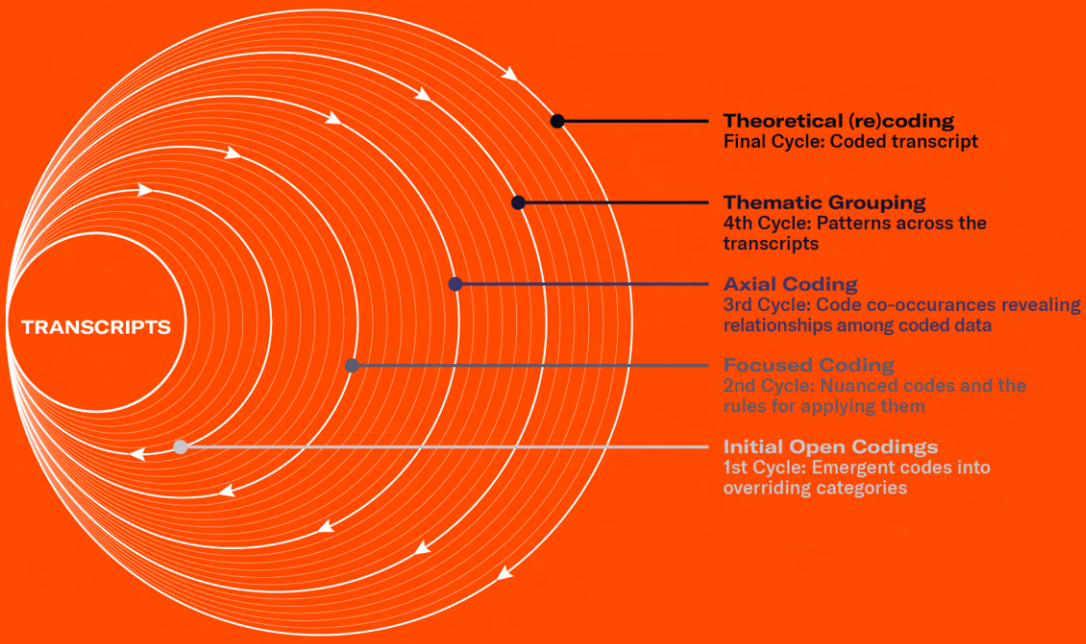
The manual process of open coding according to the grounded theory framework enabled the team to avoid over or pre-determinism in their translation of the dialogues. Coder bias inevitably manifests in the creation and application of codes that can give way

to particular interpretations. In other words, ‘you find what you look for’. Coding only for the WEF values, for example, would have imposed a deterministic model on the analysis; the grounded theory framework allowed a wider spectrum of values to be coded for, minimising the possibility of WEF-led bias.

Since the subjective nature of interpretation is inescapable, transparency becomes essential. With the codebook and coded transcripts, others can view the data-analysis process in its entirety. These materials also provide a schema for others to tell their own stories by applying new or existing codes in different ways, by targeting specific coded sections, or by critically reflecting on the prime interpretation, allowing other translations to proliferate and other stories to be told.

ITERATIVE CODING





METHOD **M5: REFLECTIONS**

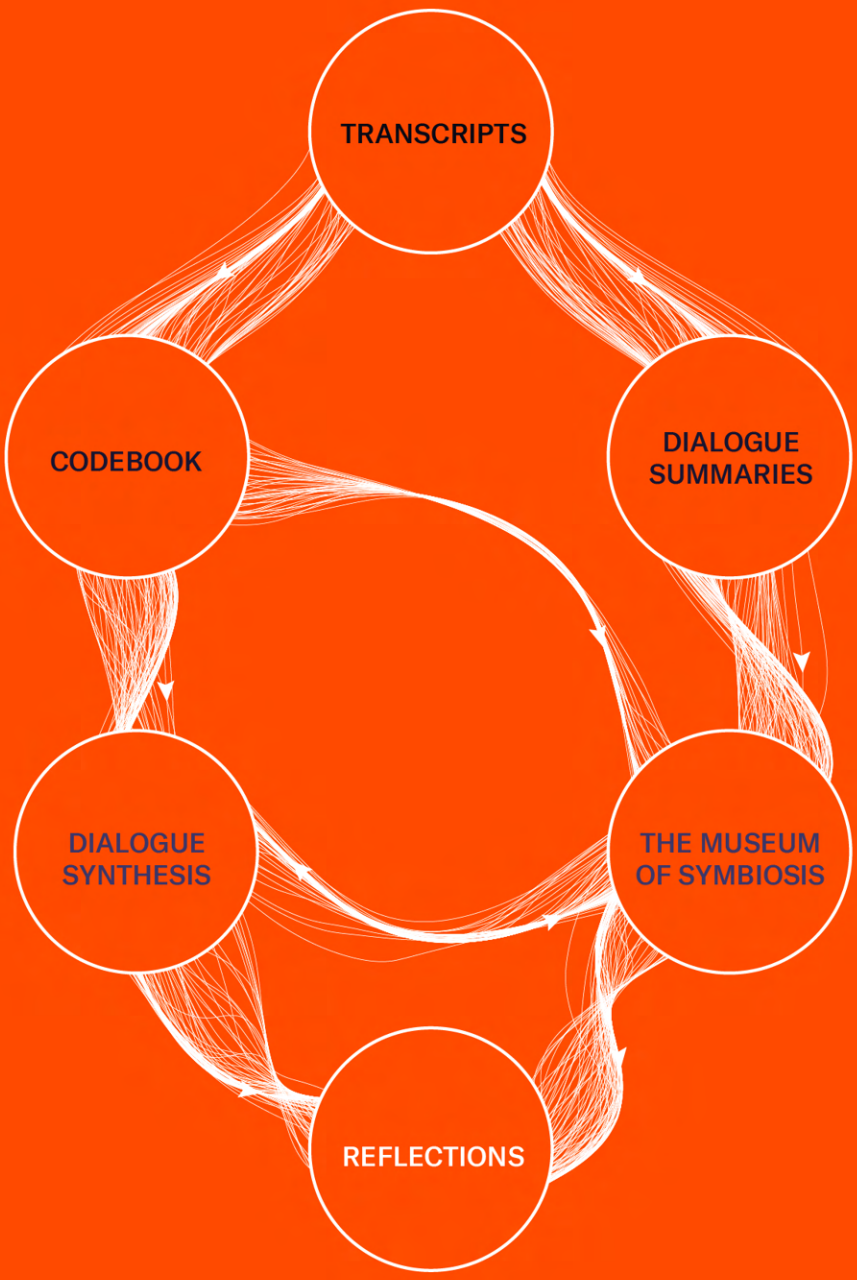
- What else can transcripts reveal through what is said and what is not said?
- What other questions could the transcripts answer?
- What other analytical frameworks could be applied and how might outcomes change as a result?
- What other stories might emerge from analysing the anthropologist's interaction with the transcripts?
- What else would you code for?

METHOD **M6: BIO STORIES: FICTIONAL AND ANALYTICAL**

BIO STORIES are plural and iterative. Of the myriad stories that could emerge from the dialogues, this iteration of the project offers two: a speculative fiction by Claire L. Evans and an anthropological analysis by Dr. Melissa Salm. Both are rooted in the careful observation of the conversations and the artefacts that ground them, precisely and respectfully translating the dialogues into relational BIO STORIES. Informed by the codebook, these accounts weave together emergent values, relationships and archetypes into compelling narratives that provide nuanced insights into the potential implications as synthetic biology evolves.

The Museum of Symbiosis collects the artefacts and insights from the dialogues into a speculative story set in a near future. Here, humanity has learned to “understand its place in the collective planetary experience”. The format of speculative fiction de-centres the position of the writer and describes a possible future that might be shaped by decisions made now. It doesn’t aim to support any pre-existing arguments but brings together these multiple embodied perspectives into a story that is more than the sum of its parts. In this context, artefacts function as connectors, material guides through common ground and prevalent themes. The story is evocative and sensorial. It hopes to inspire thoughtful consideration by synthetic biology experts and non-experts alike, and to widen access to these conversations.

The analytical story offers a grounded counterpart to the Museum of Symbiosis, clearly unpacking the modes of relating to nature and biotechnology illuminated by the dialogues, the values that underpin them and the ways of ‘being human’ they prefigure. Building on the codebook and coded transcripts, the anthropological analysis pinpoints key issues, questions and speculations from across the dialogue set. It is hoped that these can be lifted from these pages and into our practices as individuals and as a society.



METHOD **M6: REFLECTIONS**

- Once translated, to whom do these stories belong? Who are they for?
- What other modes of storytelling could be appropriate tools of translation?
- What is the purpose of a story? What effect should it have?

STAKEHOLDERS

BIO STORIES emerged around an expansive community of stakeholders and the artefacts that embody their relationships with nature. Individually, the artefacts are material manifestations of the ways of thinking, knowing and doing that each participant brought to the dialogues. However, as a collective, they start to reveal the many domains that synthetic biology can impact or is impacted by.

↓ PROTOTYPE FORUM

↓ INTRODUCTORY DIALOGUES

↓ EXPANDED DIALOGUES

PROTO**TYPE** **FORUM #1**

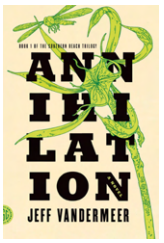

A-EVDL-01


A-MVB-03

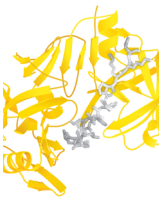

A-DK-02


A-NAC-04

PROTO**TYPE** **FORUM #2**



A-JR-05


A-RB-07


A-MM-06


A-PK-08


A-MP-09

PROTO**TYPE** **FORUM #3**

A-CA-10


A-LA-12


A-RFB-11


A-TB-13

INTRO**DUCTORY** **DIALOGUES #1**


A-GM-14


A-CG-15

INTRO**DUCTORY** **DIALOGUES #2**


A-DE-16

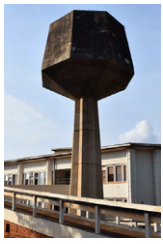

A-MM-17

INTRO**DUCTORY** **DIALOGUES #3**


A-IZ-18


A-NK-19

EXPANDED **DIALOGUES #1**


A-GO-20


A-KL-21

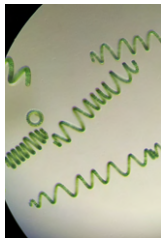
EXPANDED **DIALOGUES #2**


A-CC-22


A-JP-23

EXPANDED **DIALOGUES #3**


A-PF-24


A-KT-25

EXPANDED **DIALOGUES #4**


A-SA-26


A-FC-27

EXPANDED **DIALOGUES #5**

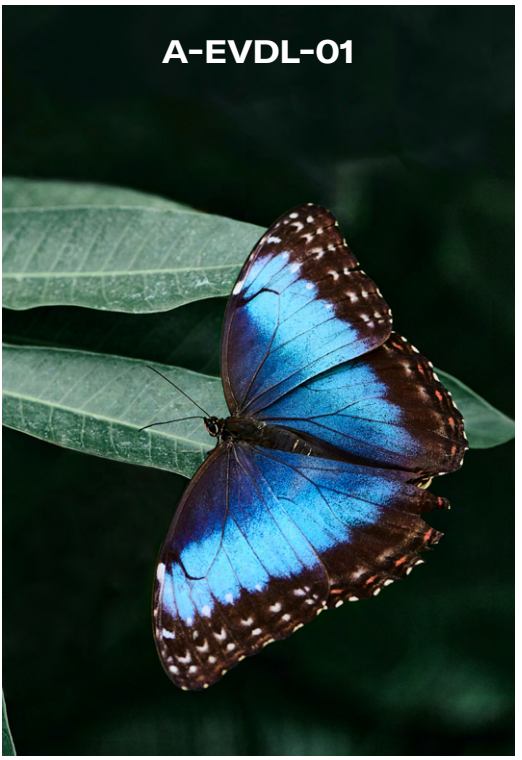

A-MB-28


A-MN-28

EXPANDED **DIALOGUES #6**


A-DSK-30


A-COT-31



A morpho butterfly producing blue color through interference with visible light. Credit: Fotostudio - All Eyes On You via Pexels.

A-EVDL-01 *"[This] is structural colour. [...] And it really strikes me because not only butterflies and animals have it, but flavobacteria [...] can also produce a structural colour in the petri dish. And I brought it because I'm a designer and of course, I really like colours [and that we] can produce colours by growing them. And maybe in the future we can programme our clothing to be blue or purple without using a chemical colour or pigments."*

Co-operative Herenboeren farm in Boxtel, the Netherlands, changing the ownership of food production from business to the consumers. Image courtesy of Douwe Korting.

A-DK-02 *"By changing the food system, we create a new playing field. [...] The collateral benefit of this is not only the food, but it's community, it's a better soil, it's more biodiversity, it's more nature. It's a nature-driven way of producing."*

Video installation inspired by Charles & Ray Eames' Power of Ten exhibited as part of the 'It's in Our Nature' sub-theme at Dutch Design Week 2021.
Image courtesy of Marleen van Bergeijk.

A-MVB-03 *"I am not only a human, but I am much more than this. There are little particles inside me. [...] The relationship between everything and nothing [is something] we should be more aware of when talking about our relationship with nature and the things around us."*

Assemblage 002, a textile dyed in collaboration with an organism called Streptomyces coelicolor, in a process of solid-state fermentation, Faber Futures in collaboration with Professor John Ward, Department of Biochemical Engineering, University College London, Commissioned by Cooper Hewitt Museum, 2019.
Credit: Oskar Proctor.

A-NAC-04 *"[There are many] possibilities when we start to work in a way that is not driven by our intentions or our expectations, but that listens to what the organism is well evolved to do already [through the] fermentation of biological systems that are more sustainable and rooted in craft. [...] And once we start talking about craft, it's impossible to not talk about communities. Who are the crafts people? What knowledge do they have to have? And what do they bring to the wider community in being able to create in this way? In other words, what is our future of bio manufacturing if it can happen at this community scale?"*

A-EVL-01 EMMA VAN DER LEEST

Emma van der Leest graduated in 2015 with a bachelor's degree in product design from the Willem de Kooning Academy in Rotterdam. Form Follows Organism: The Biological Computer is the title of her research and book on biodesign and the shifting role of a designer working collaboratively with scientists. Throughout the years Emma has worked with a number of different working materials made by microbes. She is the founder of BlueCity Lab, an experimental and prototyping laboratory in the former Tropicana water park in Rotterdam. Her goal is to lower the threshold for anyone interested in working with micro-organisms and waste streams in the development of new materials. Emma holds a research position in 'New Material Practices' at Willem de Kooning Academy and teaches at Ecology Futures Master program at Avans University.

A-DK-02 DOUWE KORTING

Douwe Korting (1974) has a background in land & water management and constructive journalism. Since 2016, he has been a board member of the world's first cooperative 'Herenboeren Farm', located in Boxtel. In recent years he has been self-employed helping to get this and other cooperative farms with around 500 co-owners off the ground. Along the way, he has embraced the valuable collateral benefits that arise in these communities.

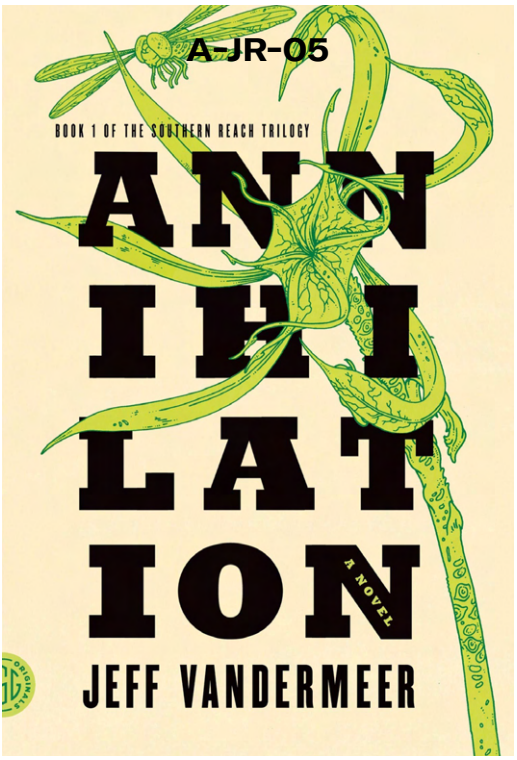
In 2020, he and two partners founded Cooperative Creabitat, which tries to develop small and large living communities. Central to this is the integral sustainable development of the areas they support. Besides the fact that people are jointly responsible for their food, they also work cooperatively on living together, shared mobility, caring for each other, nature, soil recovery, water and meaning.

A-MVB-03 MARLEEN VAN BERGEIJK

Marleen van Bergeijk is a curator and a designer. With a background in industrial design, she is fascinated by how technology has the potential to bring value to society, if designed in the right way. Her work focuses mostly on health and society, improving interaction and understanding between people. At Dutch Design Week 2021 she curated DDW's sub theme It's in our Nature, reflecting on the relationship between human and nature.

A-NAC-04 NATSAI AUDREY CHIEZA

Natsai Audrey Chieza is founder and CEO at Faber Futures. She is a leading thinker on the transformative role design can play in the equitable development of consumer biotechnology. With over 10 years of experience co-developing multi-sector innovation strategies and shaping policy with global institutions, she leads a dynamic team that translates value and transforms systems across education, design, life science and manufacturing industries. Over a decade of experimentation, Chieza established novel design-driven processes and for bacteria textile colouration, which have been exhibited internationally, including at Ars Electronica, Design Museum, Pompidou Centre, Vitra Design Museum and the Science Gallery Dublin. She is a member of the current session of the World Economic Forum's Global Futures Council on Synthetic Biology and has taught on biodesign programmes at Central Saint Martins in London and the Bartlett School of Architecture.



Annihilation is a sci-fi novel telling a story of a human expedition to a place on Earth where the usual laws of nature do not apply. See: VanderMeer, J. (2014) Annihilation. New York: Farrar, Straus and Giroux.

A-JR-05 *"We have to face this biological force [...] we now have to face the consequences of our own actions. [...] So I hope for the future for our relationship with nature to counter this kind of alienation, to get back into learning, to show curiosity to nature, to biology and face these kinds of mysteries."*

A replica of a 17th-Century microscope discovered by van Leeuwenhoek that proved the existence of microbes. Image courtesy of Maurizio Montalti.

A-MM-06 *"We came to realise that we are much more than humans, that we are [...] walking biotopes, complex ecosystems that result from the collaboration among many different types of living beings, mostly not visible to the naked eye. [This] tool enables an encounter not just with the non-human other, but ultimately an encounter with ourselves [...] Culture is nature and we are nature."*

A 3D model of an enzyme naturally residing in the stomach of calves, also used by traditional Dutch cheesemakers to convert milk into cheese.
Image courtesy of Roel Bovenberg.

A-RB-07 *"We are in a changing scientific engineering space. From a—you could say—farmer's background where we breed and optimise [...] microbes, bacteria, yeast and fungi for all sorts of industrial production, we entered a phase with genomics and DNA sequencing [...] where it gets a design aspect. [...] And this world is now on the move and is developing at a high speed. And that is what I find fascinating, including all the complexities of safety, of regulation, of dual use and also of public appreciation and acceptance."*

Fragile Future (2007) by Studio DRIFT, a light sculpture made with dandelions, Cidade Matarazzo, São Paulo, 2014.
Image courtesy of DRIFT.

A-PK-08 *"This very fragile organic thing connected with human craft then gives us a monster, an assemblage of things that don't normally hang together, right? [...] It looks beautiful and it looks natural, maybe even. But they are of a different nature [...] and not just because one is made by man and one is made organically, but also because they have a different relationship with fragility. [...] I see this as an invitation to [also] discuss our relationship with other human beings. The dandelion was used to make something pretty, but it's also a symbol of mastering nature, of putting it to use for our ends."*

A photograph of a snail trying to make its way across the sidewalk, taken by Megan during her daily walk in the Californian neighbourhood. Image courtesy of Dr. Megan J. Palmer.

A-MP-09 *"This little snail was slowly and steadily trying to make its way from one little pocket of biology to the other. And I honestly just didn't know what to do. I didn't know if I should just leave it be, knowing the next person might step on it, or should I help it along? [...] But I was also just struck by awe, awe at this little organism, wondering, what did it want? Where did it want to be? And why? Was it a simple decision encoded in the logic of the molecules underneath it or was there something more?"*

A-JR-05 JULIA RIJSSENBEEK

Julia is a researcher at the intersection of philosophy, technology and biology. She is working on her PhD in Philosophy of Socially Disruptive Technology at Wageningen University, conducting research on synthetic biology and the bio-based future. She is also a researcher at FreedomLab, a future studies think-tank that uses scenario methods to imagine alternative futures, where she focuses on the future of food and biotechnology.

A-MM-06 MAURIZIO MONTALTI

Maurizio Montalti is a designer, researcher, educator and entrepreneur. He is Founder and Creative Director of Amsterdam-based practice Officina Corpuscoli (2010), where he develops projects investigating inclusive and regenerative opportunities for the establishment of symbiotic relations among the spheres of the living and beyond. Working at the junction of design and biotech, Maurizio is one of the early pioneers committed to the study and development of wide-ranging mycelium-based technologies, focusing on the creation of multiple innovative biomaterials and of the related artefacts and products. He is also co-founder, chairman and R&D director of Mogu, the innovation-driven design company dedicated to the creation of everyday products and solutions deriving from fungi. He has extensive experience in education (Sandberg Instituut, Design Academy Eindhoven, Design Akademie Saaleck). He has exhibited globally in the Museum of Modern Art (New York), Centre Pompidou (Paris), Design Museum (London), Triennale (Milano), MAXXI (Rome) and MAK - Museum of Applied Arts (Vienna), among others.

A-RB-07 ROEL BOVENBERG

Roel Bovenberg is Senior Science Fellow of Biotechnology at Royal DSM and honorary professor of Synthetic Biology and Cell Engineering at the University of Groningen. He has a background in microbiology, biochemistry and genetics and is especially interested in the design and evolution of bacteria, yeast, fungi for the production of a wide range of products (proteins, lipids, carbohydrates, flavors, vitamins, antibiotics, biochemicals) by fermentation. The rapid developments in the biosciences and the broad potential of biotechnology to contribute to more sustainable products and processes are his continuous source of inspiration.

A-PK-08 PIM KLAASSEN

Pim Klaassen works as assistant professor in Science and Technology in Society at the Athena Institute, VU Amsterdam. His work focuses on the societal and cultural meaning of science and technology, on processes through which elements and developments in science, technology and society reciprocally shape each other, and impacts of inclusive and reflective research practices, among others in the context of environmental policy. Recently his interest has been shifting towards the role of reflection in co-productive entanglements between science, technology and society and arts-based methodologies to simultaneously promote such reflection and to investigate science-technology-society interactions, for instance in synthetic biology.

A-MP-09 MEGAN PALMER

Dr. Megan J. Palmer is the executive director of Bio Policy & Leadership Initiatives at Stanford University, leading integrated research, teaching and engagement programmes to explore how biological science and engineering is shaping our societies and to guide innovation to serve public interests. In addition to fostering broader efforts, Dr. Palmer leads a focus area in biosecurity in partnership with the Freeman Spogli Institute for International Studies (FSI) at Stanford and serves as co-chair of the World Economic Forum Global Futures Council on Synthetic Biology. For the last 10 years she has led programmes in safety, security and social responsibility for the international Genetically Engineered Machine (iGEM); she now serves as a special advisor to iGEM. Dr. Palmer also founded and serves as Executive Director of the Synthetic Biology Leadership Excellence Accelerator Program (LEAP), an international fellowship programme in biotechnology leadership. She advises and works with many other organisations on their strategies for the responsible development of bioengineering.

A photograph taken outside the New York Stock Exchange, on the day when Ginkgo Bioworks,a Boston-based biotech company, became a publicly-traded business, 2021.
Image courtesy of Ginkgo Bioworks.

A-CA-10 *"[I've been] interested in the double meaning of equity. Equity as in the shares of the company that can be publicly traded now on the Stock Exchange, but also equity in terms of justice, fairness. Those seem to be actually at odds with each other most of the time. The economic priorities of companies, of capitalism, seem to conflict with what an equitable outcome of a technology might be. [...] All of our workers, all the people who work at the company, have high vote shares [...] because we believe that people who are close to it, who are building that platform should have that voice."*

An image of cheese, 2014.
Credit: Frank Schulenburg via Wikimedia Commons.

A-RFB-11 *"This old piece of work is also subject now to synthetic biology because the proteins that are in the cheese [...] nowadays start to be produced by micro -organisms instead of by the cow. [...] And of course, I love cows and I hope they will be with us for many years to come, but we also are very much aware of the environmental burden because of cows."*

Synthetic rhino horn, developed by an American-based company, Pembient, 2015. Credit: Pembient.

A-LA-12 *"Their idea was if we just flood the market with this synthetic rhino horn we will reduce demand, it will become so abundant and the price will go down, so there won't be a need for people to poach rhinos anymore. So, yes, I thought that was a great idea. But [...] it's not really tackling the core problem here, which is that some elites in some countries have cultural beliefs about rhino horn and there will always be a hunt for actual rhino horn. Also some local communities in countries where there are rhinos, they said, well, this is just a Western-based technology from people that know nothing of our culture and trying to make something alien and introduce it, then they think everything will be solved. That's just too simplistic."*

An image of a spirulina factory; Image courtesy of Tom Bosschaert.

A-TB-13 *"[Twenty-two years ago, our brief] was to help a small desert community in Australia to figure out how to become economically relevant. Through the use of a catalytic organism, we could solve so many social, environmental and also financial problems for this town. [...] It's interesting to look at this image as I find it a rather mechanical application of the use of bio-organisms, but at the time the thinking was 'We just make a factory for spirulina' and that was it. And now we are integrating it into the urban environment and into living building systems. We see that they can have more additional benefits than if just applied as a factory."*

A-CA-10

CHRISTINA AGAPAKIS

Christina Agapakis is a biologist, artist, writer and creative director at Ginkgo Bioworks, an organism-design company that is bringing biology to industrial engineering.

Ginkgo Bioworks grows cultured products for partners across many industries. Agapakis's work brings together biologists, engineers, designers, artists and social scientists to explore the future of biotechnology. She holds a PhD from Harvard University, where she worked on producing hydrogen fuel in bacteria, creating customizable plants and making photosynthetic animals. She has taught designers at the Art Center College of Design and biomolecular engineers at UCLA.

A-RFB-11

ROB F. BEUDEKER

Rob has been active as Theme Director Nutrition and Health at TiFN coordinating public-private parternships till July 2021. Rob is also responsible for the investment in start-up companies active in nutrition at DSM Venturing. This open innovation activity is for the benefit of both the start-up and DSM.

Rob was active as VP Innovation at Human Nutrition and Health at DSM between 2010 and 2016. These activities were steered globally from Switzerland. He has an MSc in biology and PhD in microbiology from the University of Groningen in the Netherlands. He did a post-doc at the University of Texas at Austin in molecular biology after which he joined Gist-brocades (now DSM) R&D in 1984. He has been working in various functions in R&D (project-, programme- and resource management) and New Business Development at DSM ever since. He got an MBA from the Universities of Rotterdam and Rochester (NY). He is a member of the Board of Nutrileads NV, JavaFoods Ltd, S-Biomedic NV, Frontier Nutrition Inc., Phynova Ltd and Deep Branch Biotechnology Ltd.

A-LA-12

LOTTE ASVELD

Lotte Asveld is an assistant professor in Biotechnology and Society at Delft University of Technology. Her research focuses on the question of how industrial biotechnology can be made more inclusive, through design, or additional innovation management approaches.

A-TB-13

TOM BOSSCHAERT

Tom is Except's founder, director and creator of the Sustainability in Development (SiD) framework. He crafts innovative processes that drive complex systems towards resilient and flourishing futures. He steers teams using design thinking and innovation processes to pioneering results. As an entrepreneur he has founded several sustainable development organisations. As an educator, he writes, teaches, lectures and gives professional training.

A photograph of fruit baskets offered to Dr. Gillian's family as a form of condolence gift. Image courtesy of Gillian Marcelle.

A-GM-14 *"Nature and things that are natural are held in high value and are part of important moments, moments of celebration, moments of commemoration, moments of sadness. [This has a lot to do] with society's relationship to things that are natural and the values that we take into how we shape those things, how we shape who has access to nature as an asset, how we understand nature as an asset being for many generations to come and producing benefits, or whether we actually squander, damage and not value natural assets that simply make being human on the planet more enjoyable."*

A wild non-edible mushroom covered in dirt, collected by Chido at a local park. Image courtesy of Chido Govera.

A-CG-15 *"[...] that knowledge that she possessed and how she was able to convey it links to the reason today why mushrooms are my artefact because not only was she telling stories from the process of foraging the mushrooms, but her stories about mushrooms were from the behaviour that you have to carry yourself with in the forest while processing the mushrooms, while eating the mushrooms. And also she brought in the concept of gratitude, gratitude to the gods of the forest."*

Raspberry Pi 4, a portable computer and an example of personalised technology. Image courtesy of Drew Endy.

A-DE-16 *"We mostly have industrial biotechnology. So it is not a technology of the people, but a technology of industry that happens to people. So what that does is it positions all of us to be consumers of the bio economy as opposed to citizens of the bio economy. [...] Biology teaches us that all atoms are local. So that makes biology the ultimate distributed partner for making things, for growing things, for manufacturing and I think that's exactly the opposite to centralised, intensified manufacturing. It is possible to imagine a future in which biotechnology is a complement that is personal."*

BIO EX MACHINA, a bio-brick made out of interactions between fungal cells. Credit: Officina Corpuscoli & Co-de-iT.

A-MM-17 *"[This] rather utilitarian type of approach looks at the possibility of employing [...] fungal organisms and fungal cells in processes of bio-assembly. [...] But at the same time, this process of generation of matter allows for reflection on the capacity of biological living systems to express functionalities that go beyond the limitations of our current technologies. So again, it's about an expansion into what are the opportunities that emerge or could emerge when embracing an active engagement, a relationship, an entanglement with the living."*

An image of a tissue culture incubator, used in synthetic biology to grow and maintain cells. Image courtesy of Ionat Zurr.

A-IZ-18 *"Synthetic biology is very much about reductionism to the idea of the DNA as the building blocks in life. [I think] we need to contextualise life and we always need to look at what sustains life. And one of the most humble but most important things that we all have in the laboratories is the incubator. Even the way it's designed aesthetically is to almost be insignificant, almost transparent. No one talks about it, but actually, not only is it important to sustain life, it has a major effect also in the way life is differentiated."*

A pin designed by Karen Ingram, symbolising the open reading frame coding a protein. Image courtesy of Natalie Kuldell.

A-NK-19 *"I would love to engage with people in science as a process, science as an idea generator, as a way of exploration, as opposed to just cumulative knowledge that is there. [...] I would love to see people wearing these and starting conversations about them. What is that pin? What does it mean? Are you part of a club? Where did you learn this? How do I get involved? I think we can bring an open conversation that includes technical pieces. [...] We need to be able to tell people, yes, it looks like this scary scientific piece of equipment. But here's how it works. And here's how you do it. And yes, you can. The notion that science is only for some and not for others, I think we need to change that."*

INTRODUCTORY DIALOGUES #1

A-GM-14

GILLIAN MARCELLE

Gillian Marcelle, PhD leads Resilience Capital Ventures LLC, a boutique capital advisory practice specialising in blended finance. She has a proven track record in attracting investment and on telecoms, fintech, renewable energy and regenerative agriculture. Her speciality is the design and implementation of blended finance strategies that often involve partnerships, ecosystem strengthening and architectures for transformational change. Her experience includes staff roles with the International Finance Corporation, equity capital markets at JP Morgan Chase and M&A with British Telecom. As a thought leader, Dr. Marcelle developed the Triple B Framework which provides a vision and strategy to improve flows and allocation of capital in its multiple forms. She serves on the Advisory Board of Marketspace USA and has guided numerous ventures in the role of Senior Advisor. Her academic career includes a tenured Associate Professor role at Wits Business School in Johannesburg, South Africa as well as teaching and research positions in the UK and the Caribbean. Dr. Marcelle is a published research scholar and maintains academic networks; in the US, with MIT and Penn State; in Europe with SPRU, University of Sussex; across the African continent and the Caribbean. International public service includes appointments with the United Nations and the World Economic Forum.

A-CV-15

CHIDO GOVERA

Zimbabwean social entrepreneur, Chido Govera, is passionate about mainstreaming biocultural diversity for building resilience and improving the conditions necessary for individuals and communities to thrive and reach their full potential. Deeply embedded in her work approach is her commitment to giving a livelihood and a voice to the most vulnerable, especially women and girls, of communities where she works. Thus, food and nutrition security, education and socio-economic empowerment of communities are the foundation of the initiatives she implements through her organisation The Future of Hope Foundation (TFoHF).

INTRODUCTORY DIALOGUES #2

A-DE-16

DREW ENDY

Drew Endy is a bioengineer at Stanford University who studies synthetic biology. His goals are civilization-scale flourishing and a renewal of liberal democracy. Prof. Endy helped launch new undergraduate majors in bioengineering at both MIT and Stanford and also the iGEM—a global genetic-engineering 'Olympics' enabling thousands of students annually. His past students lead companies such as Ginkgo Bioworks and Octant. Endy served on the US National Science Advisory Board for Biosecurity (NSABB), the Committee on Science, Technology, & Law (CSTL), the International Union for the Conservation of Nature's (IUCN) Synthetic Biology Task Force and the Pentagon's Defense Innovation Board (DIB). He currently serves on the World Health Organisation's (WHO) Smallpox Advisory Committee. Esquire magazine recognised Drew as one of the 75 most influential people of the 21st century.

A-MM-17

MAURIZIO MONTALTI

Maurizio Montalti is a designer, researcher, educator and entrepreneur. He is Founder and Creative Director of Amsterdam-based practice Officina Corpuscoli (2010), where he develops projects investigating inclusive and regenerative opportunities for the establishment of symbiotic relations among the spheres of the living and beyond. Working at the junction of design and biotech, Maurizio is one of the early pioneers committed to the study and development of wide-ranging mycelium-based technologies, focusing on the creation of multiple innovative biomaterials and of the related artefacts and products. He is also co-founder, chairman and R&D director of Mogu, the innovation-driven design company dedicated to the creation of everyday products and solutions deriving from fungi. He has extensive experience in education (Sandberg Instituut, Design Academy Eindhoven, Design Akademie Saaleck). He has exhibited globally in the Museum of Modern Art (New York), Centre Pompidou (Paris), Design Museum (London), Triennale (Milano), MAXXI (Rome) and MAK - Museum of Applied Arts (Vienna), among others.

INTRODUCTORY DIALOGUES #3

A-IZ-18 IONAT ZURR

Dr. Ionat Zurr is an artist and a scholar. She is the Chair of the Fine Arts Discipline at the School of Design and researcher and Academic Coordinator at SymbioticA Laboratory, at the University of Western Australia. Zurr is considered a pioneer in the field of biological arts; she publishes widely and exhibits internationally. Her work was exhibited and collected by museums such as Pompidou Centre in Paris, MoMA NY, Mori Art Museum, Ars Electronica Austria, the National Art Museum of China and more. Zurr's ideas and projects reach beyond the confines of art; her work is often cited as inspiration to diverse areas such as new materials, textiles, design, architecture, ethics, fiction and food.

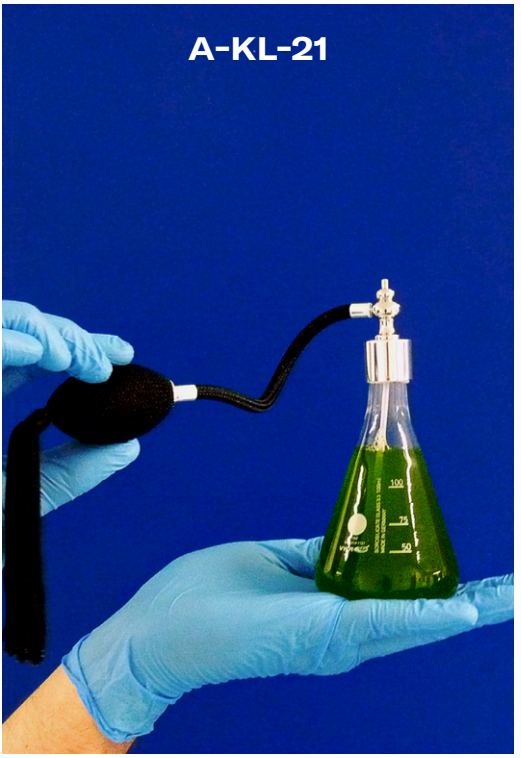
A-NK-19 NATALIE KULDELL

Dr. Natalie Kuldell leads BioBuilder, a nonprofit organisation that inspires the next generation of innovators with authentic science and engineering. BioBuilder's synthetic biology curriculum breeds excitement by helping students and teachers design and then build biotechnologies that solve real problems throughout the US and around the world. BioBuilder opened a community lab in Kendall Square's LabCentral in 2017 and a second in 2021 inside Ginkgo Bioworks.

D.r Kuldell studied chemistry as an undergraduate at Cornell, completed her doctoral and post-doctoral work at Harvard Medical School and taught at Wellesley College before joining the Department of Biological Engineering faculty at MIT in 2003. She is the 2020 recipient of the Margret and H.A. Rey Curiosity Award and the Million Women Mentors STEM Trailblazer Award.

A photo of a sculpture resembling a bacteriophage at Makerere University in Uganda. Image courtesy of Otim Geoffrey.

A-GO-20 *"Around the 1940s phage therapy went out and we did not hear it for some good time. And the reason was because there was no preferred method of purifying this. They lacked the knowledge that this phage is more selective than antibiotics [...] so if you target a bacteria that it is not specific to, it may not work. So why am I saying this? It's because now there are technologies that can be used to modify this bacteriophage, and then to bring it back to the market as a potential treatment for this bacterial infection. [...] So we can say nature is revolving and history is revisiting itself."*



A standard Erlenmeyer flask full of green algal culture, imitating a perfume spray bottle. Image courtesy of Kyle Lauersen.

A-KL-21 *"We can look at designing algae or organisms that can convert waste products into something of value. So in this case, it's perfume, which is arguably not an important thing, but it is something that people use to generate wealth and revenue. [...] So to me, this typifies one idea of what we can do. Of course, it's not the only thing we can do with synthetic biology."*

A sample of bark lace grown on a tree.
Image courtesy of Carole Collet.

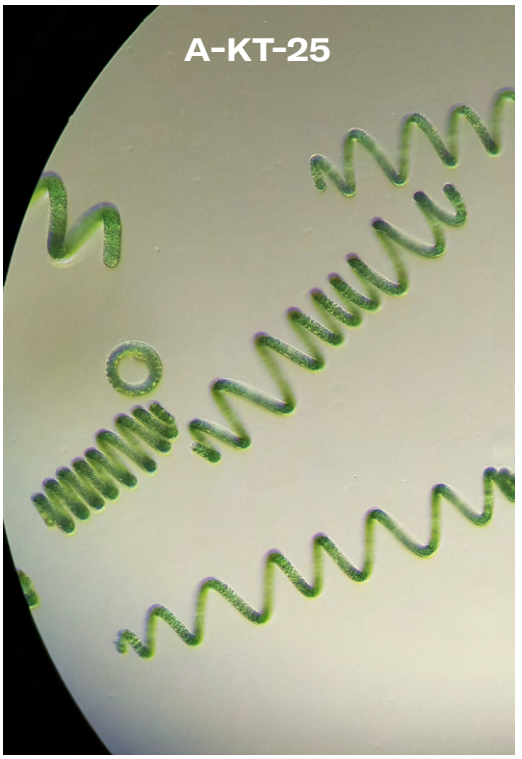
A-CC-22 *"When I look at Biolace, I'm looking at future urban hydroponic factories, which are being developed, but I'm also looking at the Milpa system, which is a very traditional indigenous way of thinking about how you can collaborate and create families of different plants that support each other through their nutrients to grow better together. And so I think for me, this notion of how as a designer I interfere or I contribute to the material world is in making sure, perhaps, that we can disrupt that false understanding that progress has to be technological. Sometimes it does and sometimes it's the only way, but I don't think we should assume it's always the only way."*

ELSA Revelator IR controlled LCD shutter glasses for NVidia based graphic cards. Spectacles design over the centuries, from classic spectacles to Google glasses, 2009.
Image credit: Afrank99 via Wikimedia Commons.

A-JP-23 *"There's this question of regulation and intervention. Is this desirable? Is this not desirable? But I think when one wants to look at it culturally the one thing that comes to mind is [that] questions of 'Is it desirable? How is it desirable?' It cannot be settled outside of context. And that context is exactly our ways of seeing. [...] What happens when we start using modes and tools that allow us to change what we are seeing? [...] What kind of a world do we create?"*

A coral shell inherited by Paul from a relative. Image courtesy of Birmingham Museums Trust Via Unsplash

A-PF-24 *"I look at this beautiful shell, the coral and I think of this beautiful romance with biology and the natural world as being wonderful and harmonious, but it's dead. Biology is just so ruthless and organisms are ruthless, which is kind of a contradiction. [...] For example, in my part of the world people would get quite upset [about] genetic modification: 'You don't know what you're doing. You're playing God,' all this sort of thing, because they have this romantic image of biology, but actually in the real life natural selection is ruthless. Organisms kill each other. [...] There is this disconnect between the realities of biology and how we can harness biology."*



A microscopic image of spirulina. Image courtesy of Kassahun Tesfaye.

A-KT-25 *"I'm always thinking how to have one thing address several issues at a time. As you know, we have a problem with food security and also with energy. So from that point of view, I always think that micro-algae, specifically, spirulina is the best solution because it is unicellular cyano-bacteria. It can serve as a food and help us to minimise malnutrition at the childhood level and at the same time it can [be used] for energy production, for bioethanol production and biodiesel production."*

A calabash filled with an indigenous red rice from Ghana.
Image courtesy of Selassie Atadika.

A-SA-26 *"[I think it's important for us to understand how to start to be able to feed ourselves and how to be able to put money back into the economy, how to create sustainability by eating what grows traditionally, naturally, better, in the soil that we have. [This] indigenous rice does not need a lot of fertiliser, so it means that the soil will actually have higher health and rather than putting all these chemicals on it, you're using what is naturally there. [...] If you have a better understanding of what yield and sustainability mean, what is considered success in the short term might actually, in many ways, be destruction in the long term."*

A jar with soil coming from Fernando's mum's garden.
Image courtesy of Fernando 'Nano' Castro.

A-FC-27 *"I think diversity was one of the things that I believe that was missing in the values. [It is] really very important in our times because all those values are related, the existence of the other and the other is different from myself, so that's where I can be humble or where equity starts. [...] I understand that there is a difference, so I can understand equity. That's why I chose this soil. And also because it's a small world in itself, only this little bit of soil. It's a small world with many worlds inside."*

A butternut squash grown in Margo's garden.
Image courtesy of Margo Bagley.

A-MB-28 "*I learned a lot of lessons from my garden, mostly spiritual ones, but also about resiliency and the importance of work and companionship, [...] and the need for outside support, sometimes in terms of pollinators like bees. [But there are also] very complex issues surrounding bio-technology, synthetic biology, intellectual property and seeds and plants. [...] Wonderful benefits can come from the genetically modified seeds in terms of pest resistance and herbicide tolerance and drought tolerance. But I wonder about the trade-offs in terms of the autonomy and freedom of farmers, going more towards monocultures in terms of reducing the biological diversity.*"

An image of a cannabis leaf known as a weed strain, Durban Poison, used locally in Durban, South Africa's KwaZulu-Natal province area, to relieve asthmatic symptoms.
Image credit: jcomp via Freepik.

A-NM-29 "*[Regarding] solutions that are Indigenous in nature, particularly the cannabis one because that's the one I suppose that's personal to me, [...] the knowledge is not being conjured appropriately, because those who have the means and the resources to conduct the research choose not to do so. It's not of interest to them. [...] When we talk about medicine, we use a Western paradigm. And so we use the notion of an active ingredient, whereas a lot of the Indigenous knowledge systems that we tend to utilise as societies, let's say, in the Global South, tend to work in a synergistic manner.*"

Two ceramic bulls called Toritos de Pucará from Puno, in the Peruvian Andes, gifted to David by one of his students. Image courtesy of David Sun Kong.

A-DSK-30 *"You must receive [the Toritos de Pucará] as a gift in order for them to have their protective function. [...] And so through the process of giving, there's a way in which the relationships that we have with the object actually fundamentally changes. [...] And I think it's part of a larger value system that I personally hope can expand and become a more entrenched part of our Western world. What does a world look like where gifting and gratitude is central to how we engage with the living world? That feels like a very important set of values for us to really embrace in this moment where we're having such challenging times in working with our ecosystems, which are in severe distress."*

A carved radish in the shape of a flower. Image courtesy of Corinne Okada Takara.

A-COT-31 *"For me, this object is really important because it's a way to engage communities through their existing cultural celebrations and honouring of biology, what they already know. [...] And so creating these spaces, we're talking about the future of ourselves and biology. That may include off-planet travel. How would we bring everyone along in that storytelling? And I think carved radishes could be a part."*

EXPANDED **DIALOGUES #1**

A-GO-20

GEOFFREY OTIM

Geoffrey Otim is a molecular biologist, science policy advocate and a biosecurity fellow with a strong interest in synthetic biology, biosecurity and biotechnological innovations. He founded iGEM Makerere University team in 2018, the first iGEM team from East Africa. He is also the founder and CEO of SynBio Africa, a forum for researchers, students, citizen scientists, policy makers and the public at large to convene and develop successful pathways for the propagation of synthetic biology technologies, products and services throughout Africa.

Geoffrey received, among others, a Biosecurity Fellowship from Johns Hopkins Center for Health Security to attend the global synthetic biology conference organised by SynBioBeta in 2018 and a Global Community Bio Summit Fellowship to attend and present at the Global Community Bio Summit at MIT Media Lab, Boston, MA in 2019.

A-KL-21

KYLE LAUERSEN

Dr. Kyle J. Lauersen is an Assistant Professor at King Abdullah University of Science and Technology (KAUST) in Thuwal, Saudi Arabia. His group focuses on Sustainable & Synthetic Biotechnology with their main research focussed on engineering algae to be green cell factories. Kyle did his doctorate at Bielefeld University in Germany and his Master's as well as Undergrad at Queen's University in Kingston, Ontario.

EXPANDED **DIALOGUES #2**

A-CC-22

CAROLE COLLET

Carole Collet is Professor in Design for Sustainable Futures at Central Saint Martins, University of the Arts. She is director of Maison/0, the CSM-LVMH Sustainable Innovation Programme and co-director of the Living Systems Lab, a research lab which explores the inherent properties of biological living systems to develop new knowledge in the field of ecology via creative practices in art, design and architecture. As an educator, she has pioneered the integration of sustainability in the curriculum by founding new courses such as MA Textile Futures in 2001 (now Material Futures) and a Masters in Biodesign in 2019. In her research, Collet questions how and what we can learn from living systems to develop inherently sustainable and regenerative design propositions. She curated the first international biodesign exhibition 'Alive, New Design Frontiers' in 2013 and has had work featured by V&A and the Pompidou Centre.

A-JP-23

JAHNAVI PHALKEY

Jahnavi Phalkey was appointed founding director of Science Gallery Bengaluru in November 2018. Previously Jahnavi was faculty at King's College London. She started her academic career at the University of Heidelberg, following which she was based at Georgia Tech-Lorraine, France and Imperial College London. Jahnavi was Fellow, Wissenschaftskolleg zu Berlin (the Institute of Advanced Study, Berlin), external curator to the Science Museum London and a Scholar-in-Residence at the Deutsches Museum, Munich. Jahnavi is the author of Atomic State: Big Science in Twentieth Century India and has co-edited Science of Giants: China and India in the Twentieth Century. She is the producer-director of the documentary film Cyclotron. Jahnavi read civics and politics at the University of Bombay and the School of Oriental and African Studies, London. She holds a doctoral degree in history of science and technology from the Georgia Institute of Technology, Atlanta.

EXPANDED **DIALOGUES #3**

A-PF-24

PAUL FREEMONT

Professor Paul Freemont is the co-founder of the Imperial College Centre for Synthetic Biology and Innovation and co-founder and co-director of the National UK Innovation and Knowledge Centre for Synthetic Biology (SynbiCITE; since 2013) and director of the London BioFoundry (since 2016) at Imperial College London. He is also currently the head of the Section of Structural and Synthetic Biology in the new Department of Infectious Diseases at Imperial. He was previously the head of the Division of Molecular Biosciences and Centre for Structural Biology having joined Imperial from Cancer Research UK London Research Institute (now known as the Crick Research Institute) where he was a Principal Investigator and Head of Group. In 2019, he led the establishment of the Global Biofoundry Alliance (GBA) comprising 23 institutions on four continents aimed at building & sharing open technology platforms for synthetic biology and is currently the chair of the GBA. His recent research interests are focused on developing synthetic biology foundational tools and cell-free systems for specific applications including biosensing and metabolic engineering. He is author of more than 250 scientific publications (H-index 76) and is an elected member of European Molecular Biology Organisation and Fellow of the Royal Society of Biology, Royal Society of Chemistry and Royal Society of Medicine and is an Honorary Fellow of the Royal College of Art. He was a co-author of the British Government's UK Synthetic Biology Roadmap and was a recent member of the Ad Hoc Technical Expert Group (AHTEG) on synthetic biology for the United Nations Convention for Biological Diversity (UN-CBD).

A-KT-25

KASSAHUN TESFAYE

Dr. Kassahun Tesfaye is Director General of the Ethiopian Biotechnology Institute (EBTi) since June 2016 and an Associate Professor of Genetics at the Institute of Biotechnology, Addis Ababa University. He received a BSc in Plant Science from Haramaya University, MSc in Applied Genetics from Addis Ababa University and a PhD in Plant Genetics from University of Bonn, Germany in 2006. He also did his three years postdoc at University of Bonn, Germany. He also worked as crop researcher and breeder/geneticist and served as center director at Sinana Agricultural Research Center, Ethiopia for two years. He provides consultancy services to various organisations and has published more than 65 articles in international journals. His main research focus is in food crop improvement using conventional, molecular breeding and biotechnological approaches to contribute to ongoing efforts of food and nutrition security in Ethiopia.

EXPANDED **DIALOGUES #4**

A-SA-26

SELASSIE ATADIKA

After over a decade spent engaged in humanitarian work with the United Nations and years of self-teaching in the culinary arts, Selassie Atadika completed course work at the Culinary Institute of America. Her company Midunu, a nomadic and private dining enterprise in Accra embodies 'New African Cuisine'. It celebrates culinary heritage where culture, community and cuisine intersect with environment, sustainability and economy by employing local, seasonal and underutilised ingredients including traditional grains and proteins to deliver Africa's bounty to the table. Chef Selassie Atadika uses chocolate as a base to feature the flavours and essence of Africa. She launched The Midunu Institute which looks to document and preserve the continent's culinary heritage. She was a finalist in the 2019 Basque Culinary World Prize, voted #73 in the Best Chef Awards 2020 and 2021 recipient of the La Liste New Destination Champion Award for Africa.

A-FC-27

FERNANDO CASTRO

Fernando 'Nano' Castro is a digital artisan from Mendoza (Argentina) working at the interface between scientific/tech communities and local communities that need to improve production practices or monitor the environment. He is also a Partner of Coop Ayllú, a cooperative that manages a small farm to produce food and beverages. Nano has given several open-source scientific tools workshops as a facilitator in Chile and Argentina. Currently, he is working on establishing an Open Agroecology Lab for soil and food research. Fernando Castro of Latam network of free scientific technologies reGOSH.

EXPANDED **DIALOGUES #5**

A-MB-28

MARGO BAGLEY

Margo A. Bagley is the Asa Griggs Candler Professor of Law at Emory University School of Law, where her teaching focuses on international and comparative patent law issues. She rejoined the Emory faculty after 10 years at the University of Virginia School of Law, where, most recently, she was the Hardy Cross Dillard Professor of Law. Margo is the lead facilitator and friend of the chair in the WIPO Intergovernmental Committee on Intellectual Property, Genetic Resources, Traditional Knowledge and Folklore and is an expert advisor to the African Union on WIPO issues. She was a board member for the Public Patent Foundation and served on the National Academy of Sciences Committee on Management of University Intellectual Property. She co-authored the first casebook in nearly a decade on international patent law and she prepared a recent report titled 'Digital DNA: The Nagoya Protocol, Intellectual Property Treaties and Synthetic Biology' for the Woodrow Wilson International Center for Scholars. Margo is also a lecturer at the Max Planck Institute's Munich Intellectual Property Law Center and at the Center for Inter-American Legal Education's programme in Havana, Cuba. Margo holds a BSc in chemical engineering from the University of Wisconsin-Madison and a J.D. from Emory, where she was a Robert W. Woodruff fellow. She also worked in industry and is a co-inventor on a patent.

A-NM-29

NHLANHLA MSOMI

Dr. Nhlanhla Msomi has had a varied career spanning R&D, academia, innovation management, policy work, corporate finance and entrepreneurship. He is the current President and Executive Chairman of AfricaBio, a Biotechnology Industry Association founded in 2000. Dr. Msomi holds a BSc (Hons) in Molecular Genetics in Biotechnology from the University of Sussex, (UK) and a PhD in Genetic Engineering from the former University of Natal, Durban. Later he completed a Diploma in Management Accounting and Finance at Varsity College, as well as the International Executive Development programme at Wits Business School. Dr. Msomi has also completed postgraduate studies in Strategy and Innovation at Oxford University's Said Business School.

Starting his work in science research (molecular geneticist, DNA mapping) he left academia in 2001 to establish a medical biotechnology firm, BioPath Laboratories (a subsidiary of Umsongo Biotechnology). Previously, he served a term as the President of the South African Society of Biochemistry, Molecular Biology and Biotechnology (the first Black person to do so). He has also served on the Boards of Council for Scientific and Industrial Research (CSIR) for two terms. He was also a Councillor on the National Advisory Committee on Innovation (NACI) for two terms. Dr. Msomi is a member of Board of Governors of the International Centre for Genetic Engineering and Biotechnology (ICGEB) in Trieste, representing the South African government.

EXPANDED **DIALOGUES #6**

A-DSK-30

DAVID SUN KONG

David Sun Kong is a synthetic biologist, community organiser, musician and photographer. He is the Director of the MIT Media Lab's Community Biotechnology Initiative, a pioneer in developing microfluidic, or 'lab-on-a-chip' technologies for synthetic biology, a collective intelligence researcher & co-creator of the "Supermind Design" methodology and a leader in the global Community Bio movement. In 2017, he founded the Global Community Bio Summit, a gathering convening the global network of community biology labs and was recognised as an emerging leader in synthetic biology as a "LEAP" Fellow. He is co-founder of 'How To Grow (Almost) Anything,' an international course on synthetic biology taught with Professor George Church of Harvard, the Bridge Program, a leadership and STEAM programme developed with Jaylen Brown of the Boston Celtics and founder of 'Metafluidics,' an open repository for fluidic systems. He also co-created 'Biota Beats,' collaborating with DJ Jazzy Jeff and other artists to make music from the human microbiome. His research has been covered via outlets such as the Washington Post, Showtime, Science, the Boston Globe, Gizmodo and STAT News. He has also performed as a DJ, beat-boxer, vocalist and rapper at hundreds of venues, his photography has been exhibited at the National Museum of American History at the Smithsonian and other museums and galleries across the country.

A-COT-31

CORINNE OKADA TAKARA

Corinne Okada Takara is a San Francisco Bay Area artist/STEAM educator who creates workshops that elevate and empower community voices in conversations centered on identity, science and technology. She conducts workshops on sustainability design and biomaterial design that celebrate existing cultural and community science knowledge. She is a Board Member and the programme director of the Salinas community biolab Xinampa. She is the co-founder of BioJam Camp, a teen programme anchored in the Stanford Department of Bioengineering. She has led four youth teams in the international Biodesign Challenge, is a 2020 Global Community Biosummit Fellow and a 2020 National Public Interest Technology Innovation Fellow. She grew up listening to her dad's stories of his Maui plantation childhood and is fascinated by the power of ancestral knowledge and storytelling in shaping the future of bio innovation. She holds a BA in Design from Stanford University.

EPILOGUE

by Cameron Fox

Two words, both Greek, followed me through BIO STORIES: *utopia* and *synthesis*.

Utopia: *ou-* (not) and *topos* (place). Ostensibly, these roots give us a word that should be defined as 'no-place' or 'nowhere.' Of course, this isn't the way we generally use the word; when we say 'utopia,' we speak of an imagined place where everything is perfect. Funny then, that we pronounce the prefix just as we would *eu-* (good, pleasant, true), a double-entendre that was not lost on Thomas More when he coined the term in 1516. This word trailed me through the Museum of Symbiosis, a place that is simultaneously nowhere and perfect, and into the Dialogue Synthesis.

Synthesis: *syn-* (together with, jointly) and *tithenai*, (to put, to place). A 'putting together,' then. This certainly befits the field of synthetic biology, but within BIO STORIES the concept resonates at frequencies above and below this meaning. BIO STORIES is itself a 'putting together,' a placing of disparate elements into a composite that becomes more than its parts. Whether those elements are intracellular machines, luminaries from far-flung fields, or cosmologies from different cultures, BIO STORIES shows us, over and over again, what can happen when we move between silos, when we slip into estuaries of material and mind and mythos.
As Dr. Faisal Khan emphasises:

> *"[...] everything that we have or that we do has an effect on our environment. We need to be mindful of not just our interactions with fellow human beings, but also with the rest of nature and even the non-living world."*

For now, those estuaries are only visible at the very edge of our perception, a fact that Dr. Matthew Chang points out when he reminds us that:

> *"[...] synthetic biology's stories are still being written."*

But perhaps through the synthesis we are just learning to grasp in the realm of science, we can find higher planes, other no-places between

individuals, between societies, between humanity and the natural world, and flip the coin from no-place to perfect place. This may seem an impossible task, but as Oscar Wilde put it, “a map of the world that does not include Utopia is not worth even glancing at, for it leaves out the one country at which Humanity is always landing. And when Humanity lands there, it looks out, and, seeing a better country, sets sail. Progress is the realisation of Utopias”.

But how do we get there? As Dr. Jane Calvert makes clear, it’s not immediately obvious that our compass is sound, that we are moving towards something better:

> *“A future that involves working with biology, abolishing money and respecting Indigenous knowledge would be wonderful. But such a future would require immense social, economic and political change... BIO STORIES gives me hope. But only a little.”*

Wilde’s quote may be inspiring, but tacitly assuming that progress is necessarily good begs questions. Progress to what end? Towards which utopia? Dr. David Bray implores us to remain:

> *“[...] vigilant of artificially convincing ourselves that what we do today is ‘for the good of all’ without anticipating un-foreseen ripple effects or unintended consequences in the years or decades ahead.”*

Indeed, a cursory scan of the 20th century will disabuse one of the notion that progress must lead to betterment, especially when one presumes to be on the path towards utopia: what means cannot be justified if you believe your ends are perfect?

There are no easy answers, but one thing is clear: as our scientific acumen increases, our moral responsibility—to ourselves, to other persons, to the planet—must increase in kind. We can no longer allow ourselves to sit contentedly in our silos—geographic, cultural, or disciplinary—ignoring the broader ramifications of our actions. We must strive to bridge the gaps, to work and create radically different maps of meaning where everyone can see themselves represented.

This responsibility underpins the goals of the World Economic Forum. Of course, striving and achieving are not commensurate, yet the point remains: the Forum strives to improve the state of the world by bringing together stakeholders from every part of society. There are few roadmaps for how this should be carried out; we are an organisation that constantly tests out new methodologies, new variations on a theme. For the past decade, one iteration of this goal has been the convening of the Global Future Councils (GFCs). The GFC network—36 thematic groups addressing topics from artificial intelligence to climate change to mental health—brings together leading thinkers across the globe to create and promote innovative solutions with the potential to shape a more resilient, inclusive and sustainable future.

In 2020, recognising a gap existed in our analysis of the most important trends shaping our world, a new GFC was created to focus on synthetic biology. Presently, it is a nascent enough field to remain unknown to many, yet for those in the know, it is clear the 21st century will be the century of biology. It is both thrilling and daunting to step into such a space. On the one hand, there is excitement in the opportunity to build from scratch. On the other, it is easy to become disorientated, agoraphobic, in a space so large and new. Where to begin?

We decided that it was essential to start from first principles, to orientate ourselves towards values reflecting our diverse perspectives. In our *Revisiting and Realising the Promises of Synthetic Biology,*[1] we lay out four concepts we believe the field must keep close at hand: equity, humility, sustainability and solidarity. From this foundation, we have begun building in several directions. Some of those pursuits are deeply practical—policy positioning, regulatory suggestions, financing mechanisms—but limiting ourselves to such concerns would not do justice to the potential of synthetic biology; the shift from taking living things apart to putting them together is too profound and strange to be contained in a white paper.

Out of this came BIO STORIES, a radically new approach reflecting the intersectionality of science, art, design and culture contained in synthetic biology. It is, at its core, an experiment, and we cannot pretend to know what the outcome will be. Why do an experiment if you already know the answer?

1. World Economic Forum (2021) Revisiting and Realizing the Promises of Synthetic Biology. Briefing Paper. [online] Available at: https://www3.weforum.org/docs/WEF_Revisiting_and_Realizing_the_Promises_of_Synthetic_Biology_2021.pdf

As with any sound experiment, we would be remiss to consider our work as an end in itself; we implore you to see it in the same light. The beauty of the scientific method rests in large part on replication, on iteration. This is where you come in: we invite you to use our methodology, to adorn and adjust it with the perspective that only you can access, to see new connections and possibilities and uses. The output is for you to decide. We sincerely hope that BIO STORIES inspires you to think differently, to ask new questions, and to find new paths into the brave new world—the utopia, perhaps—that we are rapidly approaching.

Cameron Fox is a Portfolio Lead on the Platform for Shaping the Future of Health & Healthcare at the World Economic Forum and council manager for the Global Future Councils on Synthetic Biology and Mental Health.

REFLECTION **DR. FAISAL KHAN**

In my view, BIO STORIES offers a very holistic take on synthetic biology that spans across the space and time that we currently live in.

It demonstrates and teaches us how much we need an inclusive paradigm that embraces plural perspectives. Everything that we have or that we do has an effect on our environment. We need to be mindful of not just our interactions with fellow human beings, but also with the rest of nature and even the non-living world. It also teaches how every perspective brings value to the table in unique and unexpected ways.

I work in the Global South in a nascent ecosystem which is only beginning to embrace synthetic biology. But it does so at its own pace, which may not be at par with how the field is developing. This worries me, since any 'lag' will over time grow into disparities and eventually inequities. This also worries me as such disparities also accrue as an opportunity cost for the global innovation happening in the field which is deprived of the contributions that could be made by scientists and innovators, especially the young and the marginalised, in such communities. I believe BIO STORIES helped us visualise a small but powerful glimpse of that potential.

I strongly feel there needs to be a concerted effort in helping the Global South catalyse the development of its ecosystems around synthetic biology, a preventative measure that pre-empts the disparities and resulting inequities looming in the air (like we see with other technologies such as artificial intelligence) for such communities outside the usual centres of concentration. And a dedicated effort that also helps us harness the potential all the scientists and innovators from such large parts of the world can offer to the global economy and to protecting our planet.

Some actionable items to achieve the above:

- Mobilising leaders and decision-makers in the Global South at the policy and strategy levels to begin conversations on the challenges and opportunities synthetic biology may offer, especially in their local context. This will help set the stage and define the scope of what governance and regulatory pieces need to be in place, how capital may be mobilised and how synthetic biology may (and, equally importantly, may not) help in solving local and global problems.

- Identifying and helping local champions and leaders who can be the translators and the bridge between policy circles and the communities of practice on the ground (from university PIs to high school iGEM teams) to spark these conversations. This could be served really well with a dedicated leadership programme.

- Help identify and remove barriers to the practice of synthetic biology on the ground for scientists, innovators and students. This could range from dedicated efforts to reduce barriers for scientists in the South in global consortia for scientific research (the Equity Working Group at the Human Cell Atlas being one example) to support for student teams to participate in international events and competitions that can go a long way in building trust, confidence and the very flow of ideas that science needs to flourish around us.

Dr. Faisal Khan is chief executive officer and co-founder of Peshawar 2.0, a social enterprise that is promoting technology, design and start-ups in the northwest of Pakistan and taking it to youths at the grassroots.

Synthetic biology's stories are still being written. Among these narratives, BIO STORIES' approach is notable for considering myriad stakeholders, many of whom transcend stereotypes of what synthetic biologists should be. In the process, BIO STORIES proposes what a synthetic biology-driven future might look like, should it uphold the values of equity, humility, sustainability and solidarity.

For instance, Evans' speculative fiction makes the discipline more accessible to non-experts by introducing artefacts that represent synthetic biology concepts. Through the artefacts, the piece educates readers about the top-down, exploitative paradigms that have historically governed synthetic biology, preventing equitable access to breakthrough technologies and true sustainability.

Meanwhile, Salm's anthropological analysis highlights diverse takes on the ideal synthetic biology practice. By doing so, Evans, Salm and BIO STORIES show us the tantalising possibilities of a world where pioneering synthetic biologists work hand-in-hand with traditional knowledge owners and non-traditional stakeholders to co-create products that benefit society.

At the National University of Singapore Synthetic Biology for Clinical & Technological Innovation (SynCTI), we are striving to make this future a reality by ramping up international efforts to increase synthetic biology's accessibility. Consider the Global Biofoundry Alliance, of which SynCTI is part through the Singapore Biofoundry. By providing a cost-effective means for even small companies to access sophisticated equipment, biofoundries are democratising crucial synthetic biology tools to a wider user base.

Such international collaborations, however, are only the beginning. To transform the ideals described in BIO STORIES into tangible initiatives, there are three other key steps that the global synthetic biology community must take:

- First, establish dedicated fora for all stakeholders—from farmers to design thinkers and everything in

between—to collaborate and reimagine research practice and commercialisation.

- Second, consistently incorporate varying perspectives in policy and funding decisions to encourage more equitable, sustainable and relevant research projects.

- Last but not least, continue developing synthetic biology tools that are standardised, interoperable and accessible, to ensure that the field's transformative impact is reaped by all and not just a select few.

Dr. Matthew W. Chan is the director of the Singapore Consortium for Synthetic Biology and Dean's Chair in Medicine and Associate Professor of Biochemistry, Yong Loo Lin School of Medicine, National University of Singapore.

REFLECTION **DR. JANE CALVERT**

BIO STORIES gives me hope. But only a little. I would love to believe in the utopia depicted in the Museum of Symbiosis, but I don't. I think we will continue to be oppressed by narrow straight walls and that existing incumbents will remain in power. A future that involves working with biology, abolishing money and respecting indigenous knowledge would be wonderful. But such a future would require immense social, economic and political change. And this is why I have (a little) hope. Because what BIO STORIES shows is that such a future cannot be achieved by synthetic biology alone. BIO STORIES is a shining example of a truly interdisciplinary endeavour. Its strength is the value it places on the knowledge and expertise brought by disciplines beyond science and engineering; its foregrounding of the insights found in art, design, the humanities and the social sciences; its celebration of fiction and its emphasis on in-depth qualitative (not quantitative) data analysis. This goes against the grain of much national and international policy, which prioritises funding for science, technology, engineering and medicine (STEM)-subjects that are seen to contribute to existing economic agendas—while decimating budgets for non-STEM subjects.

If these disciplinary hierarchies prevail, it is hard to imagine how we can even start engaging with currently oppressed knowledge systems and cosmologies.

Today, only a narrow range of powerful voices gets to imagine and shape the future and that future is technologically driven and builds on existing systems of exploitation and oppression. BIO STORIES shows us that if we want to bring different futures into being, governments, policy makers and international organisations will have to radically expand their conception of who should have a voice to include groups such as cooperative farmers, grassroots organisers, chefs, biological artists, biodesigners, historians and philosophers. It will also be necessary to address the forces that currently constrain scientific research: to challenge the fixation on international competitiveness, narrow economic conceptions of value and scientific excellence as traditionally conceived—requiring big grants, the acquisition of intellectual property and the concentration of privilege. It is a mammoth task to change these structures.

BIO STORIES came out of an initiative centred on synthetic biology. And its existence shows the potential within this community. But it requires a constant effort to keep synthetic biology open to people who think differently—people who are not invested in the success of this particular field. If we are to create a better future, this will require concerted attempts to build capacity not only in pipetting but also in reflecting. I have some hope, but only a little.

Dr. Jane Calvert, a sociologist of science, is a Professor of Science and Technology Studies at the University of Edinburgh.

Synthetic biology represents an incredible advancement in the precision ability of humans to reshape life—both life as we know it and life as we have yet to know it. It extends advances that humans have already been making, including farming the land, selecting certain crop species for cultivation and other activities that have fundamentally reshaped the planet Earth. The collected BIO STORIES highlight that humanity's track record as a caretaker of Earth heretofore has been spotty and could use improvement. Given this, as humanity strives to make advances in synthetic biology, we should equally recognise the importance of improving our capacity to exercise:

1. Good foresight
2. Good stewardship
3. Good safeguards

Specifically: Good foresight that incorporates new methods to project present capabilities and concerns into both near- and longer-term future projections of what our choices today will mean in shaping life, humanity and the planet Earth. While no human is omnipotent, if we are to exercise the precision ability to reshape life, then we must improve our practice of good foresight. The collected BIO STORIES highlight that we must be vigilant of artificially convincing ourselves that what we do today is 'for the good of all' without anticipating unforeseen ripple effects or unintended consequences in the years or decades ahead.

Good stewardship that embraces diversity and inclusion of different people and perspectives, as well as embracing the value of neurodiversity and the diversity of life's different processes. Synthetic biology, in its successes, must be ever-mindful not to fall into the homogeneity trap where everything becomes commoditised and loses the differences that makes life beautiful. BIO STORIES highlight that we must be good stewards of what synthetic biology creates, replaces, displaces and potentially even destroys in our efforts to improve life, humanity and Earth. This will require new ways of effectively working across different communities, ideologies,

beliefs and ways of sense-making. Good stewardship of synthetic biology requires attentive listening to the meaning ascribed to various activities by global communities.

Good safeguards that recognise we must create 'Always Be Learning Environments' (A.B.L.E.), that encourage all participants to remain curious, humble and aware that ultimately some missteps will happen and need to be addressed. The collected BIO STORIES highlight that even with an abundance of preparation and caution we perform, ultimately such learning experiences represent a fundamental part of life – to not experience them would deprive us of the chance to become better. Given the need to learn and grow, so too is the necessity for appropriate safeguards as we exercise the collective precision abilities that synthetic biology affords in creating a better future together.

Dr. David A. Bray is a Distinguished Fellow with the Stimson Center and Principal at LeadDoAdapt Ventures.

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APPENDIX

APPENDIX **DIALOGUE SUMMARIES**

To access the BIO STORIES Dialogue Summaries (including Dutch Design Week dialogues, Introductory conversations and Expanded conversations), click ↘ DIALOGUE SUMMARIES

APPENDIX **CODEBOOK: DIRECTIONS AND GUIDELINES**

To access the codebook with directions and guidelines on the coding system of BIO STORIES, click ↘ CODEBOOK

APPENDIX **BIBLIOGRAPHY**

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