EDITED BY
MARKUS SCHMIDT

# GRAIN & NOISE

## artists in synthetic biology labs

[transcript] Image

Markus Schmidt (ed.)

# Grain & Noise – Artists in Synthetic Biology Labs

Constructive Disturbances of Art in Science

[transcript] Image | Volume 221

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# INTRODUCTION

# MANAGING CREATIVE DISTURBANCES

by Markus Schmidt

"It is difficult to make predictions, especially about the future" is a well-known proverb that can easily be applied to the history of technological innovations, particularly at a time when there was no way that early developers could have anticipated the various ways in which the technology at hand would be used and implemented thereafter. What can be deduced from this historical observation is that today's scientists and engineers will also have difficulties foreseeing how their findings and inventions will alter everyday life in the future. This is not to say that predictions or probable scenarios of the future cannot be made, but just that the set of skills necessary for designing technical innovations is most likely insufficient to foresee the variety of societal and biological ramifications that these innovations will incur.

For example, while we cannot have any idea about what early humans thought about when they first controlled the use of fire, we do know that its skillful use had many implications that changed the course of human evolution. A significant amount of time was used to chew our food, resulting in the typical proto-human skull geometry that allows for strong muscles and large teeth, in addition to long intestines to digest the raw food because our ancestors before *Homo erectus*, much like chimps today, ate raw vegetables, fruits, and meat. When *Homo erectus* started to control fire and used it to cook food, the nutrient uptake was greatly enhanced, and the effort required to chew was significantly reduced. This resulted, among other factors, in an evolutionary adaptation that led to more delicate jawbones and skulls and finally to the human face with which we are all familiar. This accompanied changes in the length of our intestines (and certainly in the composition of its microbiome), leaving more time at hand for other things than chewing, such as social interactions, developing more tools, etc. So, one might say that 'fire technology' massively changed what it means to be human, and that the use of fire is now encoded in our genes (Gowlett, 2016; Parker et al., 2016).

More recent examples of far-reaching inventions include the discovery of electricity, the internal combustion engine, antibiotics, computers, nitrogen fertilizers, the contraceptive pill, the Internet, and digital currencies. While we are still dealing with the positive and negative consequences of these innovations, scientists and engineers around the world are already building the next technological toolbox, which is certain to give rise to yet another complex set of societal, economic, and environmental ramifications.

Each research field commonly undergoes three stages, roughly speaking: 1) Description, 2) Analysis, and 3) Synthesis (Danielli, 1972). The previous centuries have proven this progression for physics, from the description of how a bird flies, to the analysis of the laws of aerodynamics, to the application of these laws in novel forms such as the design and construction of an airplane for example. The same can be said of chemistry, from the description of the different forms of matter, such as the element fluorine, to the scientific analysis of its characteristics, such as fluorine being the most electronegative element known to exist (Jaccaud et al., 2020), to the creation of a large number of synthetic molecules with characteristics not found in nature, such as polytetrafluoroethylene, also known as the non-stick pan coating Teflon™.

Until the 21st century, biology never really made it beyond the analytic stage, for the most part. What if we could not just describe and analyze wild type organisms collected in nature, but instead design and construct forms of life that cannot be found in nature? This is exactly the goal of synthetic biology, a relatively young research and engineering discipline that aims to engineer living matter.

## Synthetic biology: research and global challenges

Synthetic biology is one of the 21st century's most important scientific and engineering fields. The variety of methodologies and applications range from engineered biosystems (cells, tissues, and organs) to the production of biomolecules (for medicine, food, or industrial applications), to biocomputing processes (storing, retrieving, and processing data in organisms), and even to biomachines or engineered living materials. What has been called the (immanent) Biorevolution is expected to have a far bigger economic impact than the Internet, and at the time of writing synthetic biology market estimates expect the top 400 biology applications to have a direct global impact of up to $4 trillion/year over the next 10-20 years (Chui et al., 2020).

At Biofaction, we work together with universities, research organizations, companies, and NGOs to better understand the societal ramifications of these new biotechnologies. Among others, we investigate biosafety issues (Pei et al., 2022), explore how different stakeholders see the opportunities and risks presented by these technologies, engage citizens in two-way conversations about synthetic biology, stimulate a creative process to think about the societal and environmental ramifications of synthetic biology, as part of the BIO·FICTION Science Art Film Festival for example (Schmidt et al., 2013; Youssef & Schmidt, 2020), and support the interaction between artists and scientists (Kerbe & Schmidt, 2015; Schmidt, 2018).

We undertake this work as part of several previous and ongoing research projects that demonstrate the diversity of research and engineering areas in which synthetic biology is (or can be) involved. Our recent involvement in three research projects gave us the opportunity to explore synthetic biology from different perspectives.

In Newcotiana, the goal was to apply New Plant Breeding Techniques to convert tobacco plants from a traditional crop associated with cigarettes, smoking, and cancer to a new crop that produces life-saving pharmaceutical ingredients instead (Hoelscher et al., 2018).

In SinFonia, the project aspired to replace the toxic processes used in synthetic chemistry, in the creation of polyfluorinated compounds, with a new set of biological processes that would support a more environmentally friendly production process (Calero et al., 2020).

Industrial production has massively affected the environment since the 19th century, with numerous, unsustainable processes generating tremendous amounts of waste. In Madonna, the aim was to come up with new chemical reactions, carried out by living organisms, to reverse this process in a sustainable way. The ultimate goal is to turn industrial waste into a resource, thereby closing the cycle of production (de Lorenzo et al., 2016; de Lorenzo, 2017).

### Art and science: setting up the artist-in-residence program

The scientific work required to reach these goals is clearly the most important in terms of reaching each project's objectives. A relatively small portion of the efforts, however, also go into questions of biosafety, standardization, life cycle assessment, bioethics, citizen engagement, exploitation of project results (both commercial and open access), and science communication. In addition to these activities, we aim to add yet another perspective on the work being carried out, namely by inviting artists to the laboratories who might help to shape the future in this field (Schmidt, 2018). In this book, we wanted to look very closely at the direct interactions between artists and scientists in order to learn how initial expectations and assumptions are revised, to which degree the interaction alters previous plans and conceptions about the other party, and what artists and scientists might learn from the encounter. This is a striking contrast from monographs by artists, or other publications, featuring completed artworks inspired by science or curatorial reflections about the artworks.

Biofaction initiated the organization of the artist-in-residence program. In Newcotiana and SinFonia, we had the opportunity to fund one artist each, and we could invite two artists to take up residencies in Madonna. First, we explored participating researchers' interest and willingness to host an artist in their laboratory. Scientists would not receive any remuneration or other material benefit from doing so (they already earn a salary), but would receive the opportunity to interact with an artist. The different projects have different numbers of participants (ranging from half a dozen to about 20), and we could easily find researchers willing and interested to host an artist in all projects, from either project coordinators (for SinFonia and one of the Madonna residencies) or from principal investigators (for Newcotiana and the other Madonna residency). It was the first time all of the participating scientists, their staff researchers, and lab technicians ever collaborated with an artist.

In contrast to the scientists, the residency did come with a modest financial stipend of €7,000 per artist in order to pay for the trips to the labs, to cover the costs incurred during their stay, provide means to buy some consumables and materials needed, and include the artists' personal fee. The access to the laboratory and ability to investigate what the researchers were doing, how they did it, and how they made sense of it was probably more important than the material support, particularly since a laboratory is not the kind of place where you can just knock on the door and waltz on in.

Having defined who the hosting scientists would be, Biofaction published an online call[1] for applications with information about the three research projects on various websites and on social media channels. The online call closed on June 30, 2020, having received over 150 applications for the four aforementioned residencies, with Madonna receiving about half of the applications and the other two projects about a quarter each. Applications came from European countries and the UK, but also from outside Europe such as Argentina, Armenia, Brazil, Colombia, Egypt, Lebanon, Japan, Mexico, Russia, South Africa, and the USA. Four artists were selected after a detailed evaluation process, involving the Biofaction team, two external art curators (Jens Hauser and Claudia Schnugg), and also the respective principal investigators of the research labs who volunteered to the residency in the final phase.

The artists came from different artistic fields, ranging from music and composition, to photography, filmmaking, and visual art. All of the artists had at least some exposure to science in their previous careers: Lara Tabet was a medical doctor as well as an artist, Eduardo Reck Miranda had previously collaborated with several researchers in a variety of different fields, Isabelle Andriessen looked back at one intense collaboration with a scientist, and Karel Doing, while not having collaborated with scientists previously, learned about it through conversations with his partner who is a microbiologist.

All of the preparations and selection process worked like a charm, but once the matchmaking was completed, we found ourselves amid the COVID-19 pandemic. The labs promptly closed and by the time they reopened, their administration only allowed parts of their staff back in, excluding non-essential outsiders like the selected artists. These and other events, including the complete move of one lab with 80+ people and equipment into a new facility, put a severe delay on our initial plans because we could not postpone the residencies indefinitely, but had to complete them before the official end of the projects' lifetime. Luckily, time windows did open, and thanks to the efforts of the scientists and artists, all four residencies finally took place in 2021 and in the first half of 2022.

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[1] The online call for submissions can be seen at the following link: https://www.biofaction.com/wp-content/uploads/2020/04/CALL-FOR-ARTIST-IN-RESIDENCE-2020-21.pdf.

**Karel Doing – Julian Ma (Newcotiana)**

In Newcotiana, photographer and filmmaker Karel Doing was selected to spend time in Prof. Julian Ma's lab at the Institute for Infection and Immunity at St. George's University of London. This was the first residency to take place since both parties were based in the same country, thereby easing the otherwise difficult cross-country COVID-19 travel restrictions. All of the artists were encouraged to introduce themselves to the lab team with a presentation about their own work. This had the effect of extending the number of people with whom Karel would later interact, so in addition to Julian Ma, early-stage researchers Cathy Moore and Kathrin Göritzer also became collaborators. Sharing their reflections about the residency in their chapter, it became clear that the scientists were first and foremost curious about what this collaboration would bring about. The researchers tended to categorize the residency as a form of science communication in the beginning. It became quite clear that Karel Doing's intention was not to do science communication, at least not in a straightforward way, but rather to focus on the kind of equipment, machines, and work routines that take place in the lab. While the researchers were most proud of their latest, fanciest, and very expensive machinery, Karel noted that researchers referred to a number of life hacks ranging from aluminum foil and other 'household' products to fix specific problems of their workflow in many cases. He also spent more time on artefacts, like the form and shape of research results, than the scientists would have deemed necessary, given that they were more interested in the results' abstract meaning, rather than their aesthetic appearance. Karel's focus reminded the researchers about the materiality of the machinery and physicality of the methodology that they were using, and how they were becoming accustomed to it over time.

The focus of Karel Doing's first period in the lab is not uncommon for artists who enter a laboratory for the first time. Research laboratories have a niche aesthetic with gloves, lab coats, pipettes, etc., and rules (no eating or drinking in the lab) that set it apart from other places. Observing a newcomer in the lab is always a good reminder for the scientists to perceive many details that they had previously gotten used to. After this initial 'lab phase', Karel continued with his own line of work, the so-called phytography (Doing, 2020), developing photos of tobacco plants using tobacco plant sap extracts as a developing medium and as a kind of vegetative self-portrait. Although the technique that Karel used to produce his phytographies is not the same as the New Plant Breeding Techniques deployed by Newcotiana, both show that you can do something unexpected with tobacco plants. Instead of just turning these plants into cigars and cigarettes, the plant could be transformed into a molecular factory for pharmaceuticals and cosmetics or, alternatively, one could use the plant to produce an organic developer to make analogue photos, as Karel did. The researchers and the artist convincingly demonstrated that the use of tobacco plants can be expanded beyond the status quo in ingenious ways in both cases.

**Eduardo Reck Miranda – Pablo Iván Nikel (SinFonia)**

In SinFonia, the composer Eduardo Reck Miranda was invited to visit the lab of Dr. Pablo Iván Nikel, the coordinator of SinFonia, at the Novo Nordisk Foundation Center for Biosustainability at the Technical University of Denmark in Copenhagen. Eduardo Reck Miranda is an experienced artist, having worked in numerous collaborations with researchers covering such diverse topics as whale communication (McLoughlin et al., 2018), slime mold memristors (Braund & Miranda, 2017), the brain-computer interface (Miranda & Castet, 2014), synthetic antibiotics (Miranda, 2020), and most recently quantum computing (Miranda, 2022). This wide range of topics shows Eduardo's level of curiosity and ability to explore new fields of research, pushing music making beyond conventional bounds. For SinFonia, as the name already indicates, selecting a composer and musician was considered right from the beginning. Pablo, a passionate fan of classical music, chose the acronym for the research project because he felt that it highlighted the many biochemical reactions going on in a cell at any time. Metaphorically speaking, the cell works like an orchestra that turns the elements of carbon, oxygen, hydrogen, nitrogen, phosphor, and sulfur into molecules, thereby transforming them further. The element fluorine, however, is hardly ever used in the cellular metabolism, as its extreme electronegativity makes it almost impossible to control, often disrupting the orchestra with unwanted reactions. The first encounters between the artist and the researchers took place virtually, due to pandemic restrictions, and two more lab members volunteered to contribute, Nicolas Krink and Manuel Nieto-Domínguez, following Eduardo's presentation. Eduardo quickly dived into the research topic that corresponded with the researchers' work in the weeks and months that followed. He then decided to use the enzymes' DNA sequences as informational input for his music making process; this involved partially computer-aided music and part composition.

The three researchers saw the artist's contribution as a sophisticated form of science communication, and they have laid out that Eduardo's questions triggered some interesting thoughts about potential future scientific research experiments in their chapter. Since Eduardo Reck Miranda was taking DNA sequences to make music, his idea or suggestion was to invert this process and to compose the music first, then extracting DNA out of it and to see if the resulting enzyme served any new or useful function. Could this work? Is it worthwhile to test it? The conjecture behind it is that music and genes share similar design principles, and that this similarity (or in other words, the representation of a common principle through different media) could be explored to discover solutions that are not available with contemporary enzyme design methods. Some similarities between music and genes, in particular repetition, were highlighted in the 1980s (Ohno, 1987), and Eduardo Reck Miranda's work is yet another hint that music might be able to reveal some deeper truths about DNA's design principles. Pablo Iván Nikel and his colleagues had not initially expected that the artist would make suggestions that could lead to a unique way in which their scientific work could be designed. Being somewhat surprised, they did not discard the idea right away and considered it in earnest, but eventually decided not to conduct such an unusual experiment (for now, at least). Who knows, though, maybe the cornerstone for a new set of unconventional enzyme experiments has already been laid.

**Lara Tabet – Víctor de Lorenzo (Madonna I)**

In Madonna, Lara Tabet was selected as the artist-in-residence at Prof. Víctor de Lorenzo's lab of the Molecular Environmental Microbiology Laboratory, Centro Nacional de Biotecnologia, CSIC Madrid, who is also Madonna's coordinator. Following the 2020 Beirut explosion and its aftermath, Lara eventually decided to leave her home country of Lebanon and moved to France. Like in the other residencies, the presentation of her artistic work and subsequent conversations with various lab members led to an extension of the collaborating researchers beyond the principal investigator, including Belen Calles, David Rodriguez Espeso, and Esteban Martínez. Lara Tabet was a medical doctor prior to her career as an artist and was, therefore, familiar with the world of bacteria, metabolic pathways, and lab instruments in general. These elements also featured in her recent photographic work. In the residency, however, she worked with genetically engineered bacteria for the first time.

Learning about the transformation protocols and techniques used, Lara became eager to genetically modify bacteria to perform two artworks in two separate residency sessions.

The first one involved controlling bacteria's bioluminescence through voice command. The bacteria were genetically modified to contain two new genetic constructs, one for bioluminescence, which involves the emission of light by the cells, and one that would initiate the bacterial cell's suicide when a chemical substance was present. This chemical substance was added to the bacteria using a dispenser controlled by a specific voice command, inducing a suicide reaction that would lead to the dimming of the light produced by the living bacteria. The dimming that took place after the necropoetic voice command was documented through a series of photographs and videos.

Her second artwork was, at least conceptually, less restricted to the laboratory. In response to the situation in Lebanon and the distress of its inhabitants, Lara Tabet collected bacteria from her own feces and transformed them with genes that encode Neuropeptide Y, messenger molecules in the nervous system which cause, among other things, a reduction of anxiety and stress in the human body. The freeze-dried Neuropeptide-Y-producing bacteria would, in the second part of the artwork, be flushed down a toilet in Lebanon, thereby releasing the bacteria into Lebanon's (untreated) wastewater system, potentially leading to a situation in which the bacteria would come full circle into the drinking water supply (how exactly this would happen was not specified).

Subsequently, Lebanese people, upon drinking tap water, would be boosted with an extra level of Neuropeptide Y, thereby becoming more resilient to the on-going crisis of a state on the verge of collapse. When Víctor de Lorenzo and I heard about the plans for the second artwork, we immediately infringed upon the freedom of art, as releasing a genetically modified bacteria to the environment without regulatory approval was out of the question. Flooding the water supply with a mind-altering ingredient, without approval from the human subjects exposed thereto, also resembled an enforced administration program for Soma (even though it was taken voluntarily in *Brave New World* (Huxley, 1946)). To be fair, Lara Tabet had left it open whether the release of the bacteria into the environment was planned for real or only simulated for the sake of the story, but this ambiguity was seen as problematic. Eventually, we agreed that the "scatological gesture", as Lara Tabet termed it, would be clearly marked as a performance with a non-genetically modified bacterium. Lara made effective use of the available scientific and technical know-how, access to machinery, scientific photographic equipment on several floors, even including an X-ray developing machine. When we visited the lab during her second stay, we found her well-blended into the lab, not just because of the white lab coat, but also because she quickly managed to navigate between the CSIC building's different rooms on different floors using different lab equipment for her work.

When asked what the researchers had taken away from the interaction with the artist, Víctor de Lorenzo told us that the conversations with Lara Tabet had indeed led to several reflections and further thoughts about their work, in particular related to the microbiome. In fact, Víctor had already started to talk with other researchers about potential future experiments that targeted the microbiome. How this will materialize in the future remains to be seen, but it is fair to say that the learning process was not a one-way street.

**Isabelle Andriessen – Lee Cronin (Madonna II)**

Madonna's second residency was awarded to Isabelle Andriessen who visited Prof. Lee Cronin's lab at the School of Chemistry, University of Glasgow. Due to a number of factors, including COVID-19 related travel restrictions, lab closure, and eventually the movement of the entire laboratory into a brand-new building in Glasgow, this residency was the last one to take place in May 2022. Coming from very different directions, both Isabelle and Lee are interested in the life-like behavior of non-living matter. One of the differences between their approaches, however, is the scale at which they operate: Isabelle has worked on macroscopic objects, spanning up to several meters so that it is accessible to gallery visitors, whereas Lee is more interested in meso- and microscopic performances (although part of his extensive work also deals with astrobiology). Second, Isabelle deploys chemical and physical processes such as crystallization, oxidation, and condensation that causes changes to the art objects over the course of weeks and months, while Lee aims to carry out a whole range of physical and chemical processes in a fully automated way that is controlled by algorithms, and which can yield results very quickly. This simple distinction does not capture the full range of activities, nuances, and implications of their work of course, but it does hint at the difficulties involved in bringing their different approaches together. The final outcome of the collaboration did not result in a physical artwork, but in a film; this was for a number of reasons, not least because it is really challenging to apply different lab techniques in a non-scientific setting, but also because Isabelle Andriessen was not looking for a technical extension of her work to the microscopic scale.

Not unlike Karel Doing, Isabelle Andriessen seemed to find great interest in the specific machinery and the sounds and movements that they produce. For her, not only did the machines exhibit the unusual niche aesthetic of a particular scientific tribe, but she also highlighted what could not be seen. Lee Cronin wants to fully automate the chemistry lab, doing away with typical lab tasks, gestures, and movements that used to contribute to chemists' professional identity. It is his vision that chemists will not work in a chemistry lab in the future, a disruptive approach that does not automatically create a huge endorsement among his professional colleagues. This radical vision of a fully automated future was what captured Isabelle Andriessen's interest. While the lab scientists explained their motivation, approach, and goals in a very rational way, Isabelle Andriessen thought about the implications of all of the (rationally justified) steps. The film she produced takes us to a future world in which the machines seem to be alive, carrying out their dutiful tasks and no human being is encountered in the artificial environment depicted.

One could make an analogy with the development of the computer, which started as machines the size of a factory with (mostly female) workers handling punch cards or later carrying magnetic tapes around. A look inside a contemporary computer reveals no human effort, of course, and the computational processes take place on a microscopic – actually a nanoscopic – level. In the film by Isabelle Andriessen, however, we are still on the meso- and macroscopic level, begging the question: where are the humans now, and what do they do? We will see whether these questions will still be asked by humans as we march towards a future in which machines exhibit life-like behavior.

**Summary and outlook**

All four residencies triggered a learning process among participating artists and scientists alike. The artists got to know the methods and tools used by the researchers, found out more about their conceptual approach, transforming what researchers saw in their daily surroundings, as well as finding (speculative) forms of scientific experiments that the researchers had never considered previously. All of the artists were able to extend their own artistic practices, against the background of the scientific work, by focusing on the tools and machines, on processing the data produced by the experiments, on using the research tools to modify the bacteria from their own microbiome, and on consequently thinking through the scientists' visions from beginning to end.

The participating scientists can also claim to have learned something from the interaction with the artists. It is fair to say that all scientists had somehow expected the residency – at least partially – to be an unusual and creative form of science communication, from which the artist would produce products that would enable laypeople to better understand what the researchers were doing and that this would automatically raise the research's public acceptance. In the written reflections about the residencies, it becomes clear that this initial notion rather quickly gave way in favor of an appreciation of art itself, independent of any utilitarian calculation.

The cost of participating in such a residency was not zero for the researchers, as the two early career researchers in Julian Ma's lab, for example, reported that explaining the research and supporting the artist during his time in the lab took quite some time away from their daily routines and from other important business (something we had already heard from researchers in a previous residency (Schmidt 2018)). This distraction from their actual work, the noise and grain introduced, actually comprises the core of the residency, though. Business as usual, where the artists blend in from day one, would probably not result in interesting outcomes. This leads to the question: was the outcome interesting? In the cases of Karel Doing, Eduardo Reck Miranda, and Lara Tabet, the researchers found it quite surprising and became interested in what 'else' could be done with their tools and methodologies when used in a different context. In the cases of Eduardo and Lara, the researchers were inspired to consider novel research experiments by the conversations and brainstorming sessions with the artists. Eduardo's idea to use music to come up with new DNA sequences for enzymes was eventually seen as being too far out, a bit too 'crazy' or simply as having too low a chance to succeed. Lara's suggestions and ideas, conversely, seemed plausible enough to trigger serious debates and planning among the senior researchers involved, something that they had not expected from the residency.

The four completed artworks will be shown in exhibitions and galleries and the artists will build on their experiences in the lab in the future. We cannot know how this puzzle piece of experience will be combined with other future and past puzzle pieces and what else will come out of it; this also goes for the participating researchers. What if a researcher were to observe their tools and machines more mindfully, drawing inspiration therefrom? What if someone decided to use musical composition to design better enzymes? What we do already know is that some participating researchers have told their colleagues about the artist-in-residence program, thereby triggering interest in having an artist in their lab as well. Looks like the noise and grain are here to stay.

# BIBLIOGRAPHY


01. Biofaction. (2020). Call for Artists in Residence. https://www.biofaction.com/wp-content/uploads/2020/04/CALL-FOR-ARTIST-IN-RESIDENCE-2020-21.pdf.
02. Braund, E. & E. R. Miranda (2017). On Building Practical Biocomputers for Real-world Applications: Receptacles for Culturing Slime Mould Memristors and Component Standardisation. *Journal of Bionic Engineering 14*(1): 151-162.
03. Calero, P., D. C. Volke, P. T. Lowe, C. H. Gotfredsen, D. O'Hagan, & P. I. Nikel (2020). A fluoride-responsive genetic circuit enables in vivo biofluorination in engineered Pseudomonas putida. *Nature Communications 11*(1).
04. Chui, M., M. Evers, & A. Zheng. (2020). How the Bio Revolution could transform the competitive landscape. https://www.mckinsey.com/business-functions/mckinsey-digital/our-insights/how-the-bio-revolution-could-transform-the-competitive-landscape.
05. Danielli, J. F. (1972). Artificial Synthesis of New Life Forms. *Bulletin of the Atomic Scientists 28*(10): 20-24.
06. de Lorenzo, V. (2017). Seven microbial bio-processes to help the planet. *Microbial Biotechnology 10*(5): 995-998.
07. de Lorenzo, V., P. Marliere, & R. Sole (2016). Bioremediation at a global scale: from the test tube to planet Earth. *Microbial Biotechnoly 9*(5): 618-625.
08. Doing, K. (2020). Phytograms: Rebuilding Human–Plant Affiliations. *Animation 15*(1): 22-36.
09. Gowlett, J. A. J. (2016). The discovery of fire by humans: a long and convoluted process. *Philosophical Transactions of the Royal Society B: Biological Sciences 371*(1696): 20150164.
10. Hoelscher, M., N. Tiller, A. Y. H. Teh, G.-Z. Wu, J. K. C. Ma, & R. Bock (2018). High-level expression of the HIV entry inhibitor griffithsin from the plastid genome and retention of biological activity in dried tobacco leaves. *Plant Molecular Biology 97*(4-5): 357-370.
11. Huxley, A. (1946). *Brave new world*. New York, Perennial Library.
12. Jaccaud, M., R. Faron, D. Devilliers, R. Romano, S. Riedel, & H. Pernice (2020). Fluorine. *Ullmann's Encyclopedia of Industrial Chemistry*.
13. Kerbe, W. & M. Schmidt (2015). Splicing Boundaries: The Experiences of Bioart Exhibition Visitors. *Leonardo 48*(2): 128-136.
14. McLoughlin, M., L. Lamoni, E. C. Garland, S. Ingram, A. Kirke, M. J. Noad, L. Rendell, & E. R. Miranda (2018). Using agent-based models to understand the role of individuals in the song evolution of humpback whales (Megaptera novaeangliae). *Music & Science 1*: 205920431875702.
15. Miranda, E. R. & J. E. Castet (2014). *Guide to Brain-Computer Music Interfacing*, Springer.
16. Miranda, E. R. (2020). Genetic Music System with Synthetic Biology. *Artificial Life 26*(3): 366-390.
17. Miranda, E. R. (2022). *Quantum Computer Music. Foundations, Methods, and Advanced Concepts.* Springer International Publishing.
18. Ohno, S. (1987). Repetition as the Essence of Life on this Earth: Music and Genes. *Haematology and Blood Transfusion 31*: 511-519.
19. Parker, C. H., E. R. Keefe, N. M. Herzog, J. F. O'Connell, & K. Hawkes (2016). The pyrophilic primate hypothesis. *Evolutionary Anthropology: Issues, News, and Reviews 25*(2): 54-63.

20. Pei, L., M. Garfinkel, & M. Schmidt (2022). Bottlenecks and opportunities for synthetic biology biosafety standards. *Nature Communications 13*(1).
21. Schmidt, M., A. Meyer, & A. Cserer (2013). The Bio:Fiction film festival: Sensing how a debate about synthetic biology might evolve. *Public Understanding of Science 24*(5): 619-635.
22. Schmidt, M. (2018). The Art of Antibiotics: Two residencies. Two artists. Two labs. Morawa Lesezirkel GmbH.
23. Youssef, S., & M. Schmidt (2020). Synthetic Biology and Speculative Bodies: Imaginary Worlds in Selected BIO·FICTION Films. In M. Şahinol, C. Coenen & R. Motika (Eds.) *Upgrades der Natur, künftige Körper*. Wiesbaden, Springer VS: 157-182.

# CREATIVE MIS/UNDERSTANDINGS: EXPECTATIONS, OUTCOMES, AND FRICTIONS IN ASYMMETRIC ART/SCIENCE ENCOUNTERS

by Jens Hauser

Art/Science programs, residencies, funding schemes, and institutional initiatives are currently springing up like mushrooms worldwide, illustrating the trend of an increased, mutual interest between the arts and the techno-sciences.[1] Nevertheless, while for an artist these opportunities fall within the larger scope of *artistic research* or *arts-based* research, carried out from the viewpoint of various disciplines, the inverse perspective of a natural scientist in residency or one 'embedded' in an art institution does not appear as a symmetrical reality – the typical case of conservation science in museums notwithstanding. The four artists selected for the Biofaction residency program were all invited to collaborate with laboratories in specialized areas of synthetic biology, and not only faced the figure of an individual fellow scientist as their alter-ego, but also the whole context of collaborators and teams obeying lab-specific sociological patterns and hierarchies,[2] safety concerns, ethical issues, and what philosopher of sciences Hans-Jörg Rheinberger has

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[1] The concept of 'techno-sciences' emphasizes that knowledge derived from scientific study is not 'pure', but deeply entangled with its technological tools and socio-political contexts. Philosophy points to the strong interactions in contemporary scientific research and development between formally separated theoretical science and practical technology. The term is most often ascribed to Gilbert Hottois who has coined the term in his article *Ethique et techno-science* (Hottois, 1978).

[2] Bruno Latour and Steve Woolgar were among the first anthropologists and sociologists to study the daily work processes of empirical researchers at a scientific laboratory. Their book *Laboratory Life. The Social Construction of Scientific Facts* was published by Princeton University Press in 1979.

described as "epistemic things" (Rheinberger, 1997) – tools and agencies, e.g., model organisms and technical apparatuses. Rather than the mantra-like or putative binary of art/science or stereotypes about mindsets, it may well be the asymmetry inherent in such institutional encounters that generates disturbances, interferences, or 'noise'. However, it may be these exact misunderstandings that might turn out to be fruitful and conducive to productive friction in the end (Hauser, 2021).

## Mis/Understanding

Comparing artists Isabelle Andriessen's, Karel Doing's, Lara Tabet's, and Eduardo Reck Miranda's initial proposals and expectations with the outcomes and reports at the end of the four residencies reveals different degrees of accurate predictability, mis/understanding, and mutual adaptation unfolding into tangible results. Each case appears to be specific, encountering different types and extents of 'noise'. However, in philosophy at large, and in hermeneutics in particular, "injecting noise into the system" and the "necessity of misunderstanding" (Rasch, 1992) are often considered to be something positive, "an indispensable means by which information is generated [...] noise can be perceived to be something other than interference" (Ibid:66). French philosopher Michel Serres even describes noise as "a sign of the increase in complexity" (Serres, 1982), which "erases an order and reconstitutes another order. Noise destroys and noise can produce" (Ibid:243), so that informational parasites are always present and even "inevitable, like white noise. White noise [bruit de fond] is the heart [fond] of being; parasitism is the heart of relation" (Ibid:42). The central key in this argument is that the ideal of understanding, as tacit agreement or overcoming of distance, can itself have negative effects –

> "as a gesture to extinguish difference in its relentless pursuit of the absolute presence of unified knowledge. Rediscovering oneself in the Other, the argument goes, is tantamount to denying the absolute otherness of the Other." (Rasch, 1992:62)

Transposed to the asymmetric relationships between artists and (natural) scientists this means that by understanding each other too smoothly, "one has already surrendered one's otherness to the Other and become the Same, one has been swallowed up and made to agree in advance to one's own appropriation" (Ibid:62). In this sense, one may even "include noise as an act of self-preservation" (Ibid:64). Such a position is based on information theory models, such as those outlined by Claude Shannon, which identify "information not with order, as one might expect, but with maximum disorder. To do so, the notion of information has to be distinguished from the notion of message. Information is seen as the total field of choices from which the choice of the correct message is to be made." Consequently, "an addition of noise, of perturbations in the system, means an increase in uncertainty and thus increase in information" (Ibid:65). When will an artist feel swallowed up, or a natural scientist within his institutional framework, protected and enclosed as though in the armor of legislations and health and safety concerns, will first and foremost wish for their message to be understood?

Such encounters and entanglements may not be seen as a new paradise of interdisciplinarity. Instead, they continuously provoke misunderstandings – however fruitful they may be for all of the actors engaged in such relationships, as well as for outside observers – because their focus is often placed on different finalities and methodologies of understanding, researching, and communicating. Artists may be attracted not only by the scientific research questions at stake, but also by the sophisticated technological media and apparatuses made available to them. While some researchers in the natural sciences may consider art as a pluripotent catalyzer of thought for alternative problem solving, others may still stereotypically apprehend collaborations with artists in terms of 'beauty', 'creativity', 'virtuosity', or 'genius'. Alternatively, and driven by a clear utilitarian mindset, they might expect an artist to assist them in visualizing their findings or to communicate their results in a more convincing way to their community. There may also still be artists who, when crossing the threshold of a scientific laboratory, will first and foremost perceive of an army of technicians potentially at their service, inclined to materialize their preconceived ideas. Such misunderstandings will rarely be fruitful.

## Questioning binaries

Binary thinking needs to be overcome in order to turn participants' different expectations and institutional constraints into productive tension. Is the art/science dualism, inherited from the two cultures debate initiated by C. P. Snow,[3] the most prominent point of reference since the 1960s, even still a valid mode today, waiting to be actualized by a much desired "third culture" (Brockman, 1995)? Some fundamental questions need to be raised: Why is it that only the natural sciences are still considered the only 'true sciences'? Why does the very notion of the 'humanities' not include the status of science as claimed in the German term of *Geisteswissenschaften* coined by Wilhelm Dilthey[4] with the intention of considering research in the humanities to be of equal value to the natural sciences? Dilthey's goal was to establish *Geisteswissenschaften*'s proper methodological foundation, as distinct from, but equally 'scientific' as, the so-called natural sciences, which he considered to be at risk of becoming reduced to positivist cause and effect logics, thereby neglecting the complex relationships at stake with regards to human 'understanding'. To go even further: Why are the arts, then, so often associated primarily with the humanities, and not with engineering, while many practitioners today (especially in the media arts) have a background or a focused interest in the natural sciences, and highly specialized expertise in the most diverse technologies? How can one see the arts then, today specifically, as natural science's 'natural other'?

Natural scientists often aim to clearly distinguish themselves from engineers, though, in a way comparable to artists distinguishing themselves from designers. "Technology and engineering are about doing new things, i.e., bringing otherwise non-occurring items into existence. Technology both enables and empowers science, but it is not science," Víctor de Lorenzo writes in his contribution to this book.[5] Artists and scientists generally converge in their desire to reflect on *how they know what they know*, instead of straightforward utilitarianism with regards to the subsequent tools that they use. While the techno-sciences have themselves become powerful producers of aestheticized images, art is no longer merely concerned with the

[3] *The Two Cultures* was an influential lecture held in 1959 by Charles Percy Snow. Snow's main thesis was that Western society was irreconcilably split into two cultures – the natural sciences and the humanities.

[4] Wilhelm Dilthey (1833-1911) was a German philosopher known for his distinction between the natural and human sciences, claiming that the main task of the natural sciences is to provide causal explanations, while the core task of the human sciences is the understanding of the organizational structures of human and historical life.

[5] De Lorenzo, Víctor: "Towards a new covenant with nature – starred by environmental microorganisms"; this volume.

aesthetic transposition of knowledge, but with knowing and feeling *how knowledge is being produced*. In this sense, the very notion and finality of the term 'research' needs to be questioned too, taking art's inherent feature of criticality towards established structures into account: One can either conduct research to find a solution or an answer to a problem or analytic question, or conduct research with the aim of generating new questions.

## Productive noise

Among the four artists selected, Eduardo Reck Miranda (a musician and composer with a scientific background) probably encountered the lowest level of noise in his residency process. His original intention to "embody a metaphorical model" of bio-fluorination "to compose a symphonic piece" also anticipated the Technical University of Denmark's Center for Biosustainability Lab's supposed interest in producing in "an effective medium for public outreach and dissemination" and the prospect of "a paper for publication."[6] The digital composition process did not seem to have encountered any regulatory obstacles since a composition "informed and inspired by a metabolic process,"[7] which the artist got familiar with, used "data abstracted from phenomena other than music," rather than working towards a wetware-based performative piece, and the artist worked with the whole team of scientists to "articulate the role played by science in my creative process."[8] By contrast, Isabelle Andriessen's initial motivation to develop materials, larger scale and new-to-nature reactions, sculptures, landscapes, and public performances was put to a reality test when actually interacting with the Cronin Lab at the University of Glasgow: "I imagined the outcome of his research to be in a much more physical or material stage than actually feasible in real life." Since "[The Cronin Lab's] materials on a molecular scale [are] oftentimes only visualized in mathematic equations and, if you are lucky, recorded in petri dishes" and the artist's crucial aim is "the bodily encounter with the time-based sculptures," she radically changed her project and finally shot "an uncanny surrealist science-fiction film, in which the Cronin Lab functions

[6] Miranda, Eduardo Reck: Motivation letter to Biofaction, 2020.

[7] Miranda, Eduardo Reck: "Making music with enzymes"; this volume.

[8] Ibid.

as an environment or a landscape in which the film's narrative unfolds,"[9] embedding the lab's automated 'chemputers' as main actors in a narrative plot in which alternative life forms are created. While "the research team and surrounding staff members were very welcoming and helpful throughout the entirety of the residency," the artist regrets that during the artistic production time itself she "had very little or no response from Lee Cronin, nor any leads or follow-ups from him or his team members. This resulted in a lack of a sense of collaboration or exchange,"[10] and initially intended to exchange philosophical discussions about and critical views upon the perspective of synthetic biology, which her residency fell short of.

Likewise, artist Karel Doing's intention to work with the actual tobacco plants modified with genome editing techniques such as CRISPR/Cas9, agroinfiltration, and intragenesis at the Institute for Infection and Immunity of St. George's University of London knocked against GMO regulations and health and safety rules, so that he finally started to grow his own, non-genetically modified tobacco plants from seeds at home. However, since his interest was indeed in the "common ground [...] between the material and processual nature of both the arts and the sciences," he turned his collaboration with the lab toward "visualization techniques that can be used to confirm the manifestation of certain bacteria, viruses, enzymes, or proteins, [...] gel electrophoresis, dot blots, and Elisa plates," because "these methods rely upon biochemical reactions that are similar to the reactions that occur in analog photography."[11] Alongside the application of his own particular technique of phytography – using the tobacco plant's juices as developers to produce photographic images of the very same tobacco plant as metonymic self-portraits – he also employed classical photography to poetically portray lab equipment: "In this way, the lab suddenly turned into a space filled with sculptures, installations, and performances, simply by allowing for an artistic point of view to be included."[12] However, his interest and desire to exchange about the origins and social and spiritual significance of the tobacco plants in indigenous cultures was not met by his scientific

[9] Andriessen, Isabelle: "Souls from the deep: a survey through a sticky universe"; this volume.

[10] Ibid.

[11] Doing, Karel: "Tobacco: a mass of atoms, a biofactory, a generous friend"; this volume.

[12] Ibid.

counterparts: "They were mostly concerned about the image of tobacco as unhealthy, and public critique of GMO technologies, which could compromise their research,"[13] so that the final aesthetic outcome was formally compelling lab photographs, prone to produce positive outreach.

Finally, Lara Tabet's residency project also took a different direction than the imagined audio-visual art piece, combining gathered scientific data, footage, images, and sound – but, in her case, it turned into a concrete, hands-on experience of actually staging conceptually challenging lab micro performances (Hauser, 2020). Both works revolve around the question of "how can we discuss agency and labor in wet media art?"[14] In the first case, the artist, who also has a medical background herself, programmed bioluminescent *Pseudomonas putida* bacteria to 'commit suicide' upon voice command; in the second case, she used and genetically engineered her own fecal bacteria to produce a psychoactive neuropeptide, and speculated on its potential release into Beirut's water system in order to increase humans' resilience and reduce post-traumatic stress disorder. To comply with the regulations of the National Center of Biotechnology in Madrid, the solution was that the micro performances at microbial scale "should take both the specific demographics of the bacterial cycle of growth and the spatiality of the laboratory setting, in which contamination can be avoided, into account. This meant that the final work would definitely have to be the documentation of the performance, rather than the performance itself,"[15] as regularly happens when documenting human-centered performance art. These artistic projects "were the subject of countless discussions around assessing their technical feasibility, their safety, and the message to be shared with the general public" for the collaborating researcher – for whom "having an artist visit an experimental laboratory was as unusual and exotic as it could get" – since the question was considered legitimate and relevant from a scientific point of view, "whether or not the deliberate spreading of mood-influencing bacteria through a large human population could ultimately have serious social consequences, even political ones, given that our perception of reality could be modified at a large scale."[16]

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[13] Interview with the artist, Paris, 10.5.2022.

[14] Tabet, Lara: "Multiscalar forms of resistance: the molecular switch, the bacterium, the individual, and the state"; this volume.

[15] Ibid.

[16] De Lorenzo, Víctor: "Towards a new covenant with nature – starred by environmental microorganisms"; this volume.

Víctor de Lorenzo describes the mutual benefit of these exchanges:

> "We were thrilled to witness how bringing an artist like Lara to our laboratory inspired her creative agenda in directions that she had never probably explored previously. We should note, though, that inspiration was bidirectional: we also discovered perspectives that we had never contemplated regarding our intimate interplay with the microbial world by talking to her. "[17]

**Analyzing motivations**

Many initiatives that boost interdisciplinary artistic research embed 'hands-on' practice of discovering possible futures by addressing the techno-sciences' deceptively seamless influence which increasingly determine our world today, both physically and mentally, something that has been addressed by theoreticians such as Helga Nowotny as the "scientification of society" (Nowotny et al., 2001), while their pervasive entanglement with their technological tools and socio-political contexts are often overlooked.

In a similar way, the Max Planck Institute's recent initiative KLAS (Knowledge Links through Art and Science)[18] has been investigating the mutual benefits of art-science collaborations related to the vast research field of synthetic biology and its public perception and understanding. In order to justify its utility or usefulness, KLAS conducted extensive interviews about the participants' personal experiences in relation to their conceptual and methodological exchange.[19] Some typical patterns, which are indicative of asymmetric expectations, also appear in these interviews. Questions articulated by biologists include: "What I can learn from artists? To be designers. They could help design our microfluidics channels," and express affirmed utilitarian desires with regards to the tools of research themselves. Othersnatural scientists hope to benefit from artists' communication skills with regards to "public engagement: if the artists can help with our work, that would be useful" or "I have learned to better explain my work to people

[17] Ibid.

[18] For more info, you can visit: https://klas.polyhedra.eu.

[19] To see more: https://polyhedra.eu/wp-content/uploads/2017/12/KLAS_workshop_booklet.pdf.

outside my field." Some participating cultural practitioners, for their part, think that "artists can certainly contribute for the advancement of science, a field that requires both imagination and creativity." Interestingly, these interviews reveal aspects that show an enhanced willingness to engage in critical self-reflection on both sides. Influenced by the artists' presence, a biologist addresses their epistemological blind spots as follows:

> "One of the biggest temptations facing scientists today is the use of high-end technology instead of reason. [...] If we are given a 'technological' solve, we would rather just throw everything in a machine and see what comes back. A lot of artists have noticed this back and forth with technology, while a new technology can help us see something differently, it can also obscure or distract from the original intention."

This last aspect points to a specific, potential benefit that the arts can provide for the natural sciences, as highlighted by Hans-Jörg Rheinberger; namely, to work against natural science's (oftentimes) uncritical use of metaphors and 'media blindness':

> "There is a general tendency on the part of scientists to blend out the epistemic dimension of their work: the ever-changing means and media. [...] They tend to look through them, [...] to view them as allowing [...] immediate access to the 'findings'." (Rheinberger, 2011:95)

## A taxonomy of role models

It is worth asking whether art/science interactions, which are often framed at an institutional level, can be abstracted from the constraints that are inherent to their respective individual or collective frameworks. Idealists may hope for new Leonardos[20] and Frank Malinas[21] to emerge, but such

[20] It is impossible to establish an exact number of publications or programs that evoke Leonardo da Vinci (1452-1519), the Italian polymath of the Renaissance, in order to idealize the reconciliation of artistic and scientific creativity.
[21] Frank Malina (1912-1981) was an American aeronautical engineer and painter, especially known for being a pioneer in both the art world and in the realm of scientific engineering.

hybrid figures, acknowledged by both sides for their expertise, remain extremely marginal. In addition, a sort of homogeneity is often misleadingly assumed with regards to what happens when a cultural practitioner crosses the threshold of a 'laboratory'. Oron Catts, artist and co-founder of SymbioticA, the internationally renowned laboratory at the University of Western Australia in which artists can acquire scientific methods, has criticized the vagueness of the term 'lab' and has described the (quite different) roles that an artist might take on when entering a life science lab:

> "1) the illustrator, 2) the commentator/representer, 3) the visitor/guest/onlooker, 4) the appropriator, 5) the entertainer, 6) the user, 7) the industry worker, 8) the hoaxer, 9) the hobbyist/amateur, 10) the after-hours/under-the-table, 11) the mail-order/ready-made, 12) the researcher/embedded in science/technology setting" (Catts, 2008:120).

In addition, artists in labs may be tempted to creatively turn their dealings with, or struggles against, their hosts into an attitude known in the context of art as the genre of 'institutional critique', thereby conducting their own laboratory studies in a resolutely post-Latour-ian way. Should all natural science labs have an artist-in-residence? What might be, then, natural scientist's motivations and roles when enabling such artistic residencies? Mirroring Catts' taxonomy, several postures come to mind:

> 1) the idealist believing in sharing creativity and curiosity *inter pares*, 2) the opportunist prone to appropriate virtuosity and celebrity, 3) the utilitarian trying to address ethical questions via the arts, 4) the epistemologist believing in alternative ways of knowledge production and discovery, 5) the PR manager employing art for public outreach and agenda setting, 6) the hidden artist striving for recognition by pairing up with artists, 7) the aesthete looking for stylish and beautiful art decoration, 8) the sociologist challenging lab hierarchies through the artist's presence, 9) the businessman engaging in spectacular co-productions, 10) the educator looking for alternative pedagogical strategies, 11) the designer looking for innovative solutions, 12) the philosopher aiming to question and critique techno-scientific reasoning.

However, while this current trend of an increased mutual interest between the arts and the techno-sciences might be addressed as an 'epistemological turn' – it not only results in the production of new forms and narratives but also unfolds in poetic and critical ways of alternative knowledge production, especially including hands-on practices with shared media, materials, and matters. Weary of the gilded cage of metaphor and representation, symbolic intervention, formalistic evocations, or critique at a safe distance, such techno-science related artistic strategies call for an analysis that is not based primarily on imagery, but on material media and epistemic connections; meanwhile, the techno-sciences themselves have become powerful producers of aestheticized images today. Phenomena that once assumed the form of artistic images are being translated, scattered, and fragmented into a variety of instances of mediality – they are not only means to an end, but are fully integrated elements of the aesthetic object itself.

# BIBLIOGRAPHY


01. Brockman, J. (1995) *The Third Culture: Beyond the Scientific Revolution.* New York: Simon & Schuster.
02. Catts, O. (2008) Contribution to an online-symposium. In: Anker, S. & Talasek, J.D. (Eds.), *Visual Culture and Bioscience. An Online Symposium*. Baltimore: University of Maryland, pp. 120-121.
03. Hauser, J. (2020) Microperformativity and Biomediality. In: *Performance Research 25*(3), pp. 12-23.
04. Hauser, J. (2021) Fruitful misunderstandings: Artistic research in art/science within the epistemological turn. In: *Sztuka i Dokumencja / Art & Documentation 24*, pp. 151-157.
05. Hottois, G. (1978) De la marginalité philosophique en milieu techno-scientifique. *La pensée et les hommes* 22, pp. 111–116
06. Nowotny, H., Peter, B. & Gibbons, M. T. (2001) *Re-Thinking Science: Knowledge and the Public in an Age of Uncertainty*. Cambridge: Polity Press.
07. Rasch, W. (1992) Injecting Noise into the System: Hermeneutics and the Necessity of Misunderstanding. *SubStance 21(1)*67, pp. 61-76.
08. Rheinberger, H. (1997) T*oward a History of Epistemic Things. Synthesizing Proteins in the Test Tube*. Stanford: Stanford University Press.
09. Rheinberger, H. (2011) Risking Reason: The Productive Tension of Art and Science the Work of Paul Vanouse. In: Hauser, J. (ed.): *Paul Vanouse – Fingerprints. Index – Imprint – Trace*. Berlin: Argobooks.
10. Serres, M. (1982): *The parasite*. Baltimore: Johns Hopkins University Press.

NEWCOTIANA

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# NEWCOTIANA

Tobacco (*Nicotiana tabacum*) is a commercial crop that is used to produce the eponymous product for cigarettes, cigars, and pipes. Some major cigarette companies are now committed to end smoking, given the overwhelming scientific evidence that smoking is harmful. Tobacco plants can also be used for other purposes that are clearly beneficial for health, however.

Newcotiana explores these new possible use cases of tobacco plants. The project combines several New Plant Breeding Techniques to produce high-value substances in tobacco plants (specifically in the cultivated crop *Nicotiana tabacum* and in its wild relative *Nicotiana benthamiana*) by turning their leaves into efficient plant factories for medical, pharmaceutical, and cosmetic products. For this purpose, the project's scientists are using technologies such as genome editing (CRISPR/Cas9), agroinfiltration, grafting, and intra-genesis. In this way, tobacco will be bred to produce vaccines, antibodies, and other health-promoting substances including anti-aging or anti-inflammatory compounds, thus potentially transforming the declining tobacco cultivation in Europe into an innovative and sustainable agricultural sector.

# JULIAN MA - 
## THE INSTITUTE FOR INFECTION AND IMMUNITY

By developing a better understanding of pathogen biology and human immune responses, the Institute for Infection and Immunity at St George's, University of London, works to enhance diagnosis, prevention, and treatment of infectious disease and conditions linked to immune system function.

# Karel Doing

Karel Doing is an independent photographer, filmmaker, artist, and researcher, investigating the relationship between nature and culture. He developed “phytography”, a photography technique that combines plants and photochemical emulsion, and investigates with it how culture and meaning can be shared between the human and the vegetal realm.

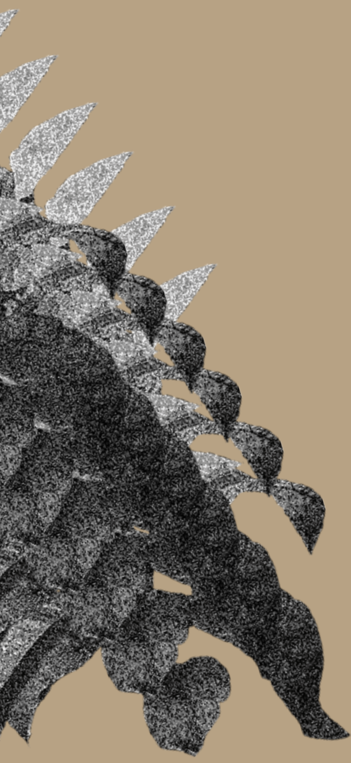


fig. 1.1 *Newcotiana benthamiana* is a tobacco plant that is used in laboratories as a model organism for both experiments and genetic engineering.

# TOBACCO: A MASS OF ATOMS, A BIOFACTORY, AND A GENEROUS FRIEND

by Karel Doing

I have been exploring new forms of meaning-making through a co-creational approach that involves plants as signifiers over the course of the past five years. I have dubbed my technique "phytography" (i.e., writing with plants) (Doing, 2020). Phytography is a form of photography that I developed by modifying and expanding established photochemical processes. My technique is deceptively simple, given that it is based on household chemicals and requires very few specialized tools and/or *a priori* knowledge. This technique has opened up many new avenues for me as an artist, educator, and researcher. In 2020, I successfully applied for an artist-in-residence program organized by Biofaction. What follows is a reflection on this residency at the Institute for Infection and Immunology at St. George's University, London. Plants are being studied in a surprising context in this research laboratory, hence the connection to my work.

The relationship between plants and photography is not at all obvious. Plants can certainly be objects when placed in front of a camera. These images are classified as 'still lifes' and are compositions of inanimate objects that can be read as metaphorical signs. Obvious examples include the sexualized fruits and flowers that appear in Robert Mapplethorpes' work. These photographs are grouped together with Mapplethorpes' openly homoerotic nudes, according to art historian Peter Schultz, and are consistently described as "symbolic representations of male genitals" (Schienbinger, 1996). In this scheme, a fruit or a flower transforms into a carrier of meaning, transcending beyond its usual inanimate being in the world. Signification is assigned to the plant by the photographer by means of precise lighting and composition.

Even plant taxonomy has not always steered clear of similar analogies and the resulting controversy. Linnaeus, who is widely seen as the founding father of modern taxonomy, based his classification system on plants' reproductive organs. As Londa Schiebinger highlights in her article about the famous scientist, “bloody and protracted battles erupted almost immediately over the scientific and moral implications of Linnaeus’ classification system” (Schiebinger, 1996:110). His ideas were seen as obscene by some of his contemporaries, but Linnaeus himself attempted to project an idealized view of gender and marriage onto the plant kingdom, contradicting his own methodology in the process.

Another possible appearance of plants in photography and film is not as clearly imbued with meaning; namely, their appearance in the background or as part of the background. However, plants might have more agency than expected in this case. The ‘accidental’ appearance of nature in photography and film is regularly discussed in cultural theory as one of the medium’s unique properties. This is often exemplified in the literature by the movement of leaves in the film *Le Repas de Bébé* by the Lumières brothers (1895), something that was widely admired by the audience as a captivating element. Avant-garde film director Maya Deren comments on this often-overlooked aspect of photography in a pertinent way:

> “Only in photography – by the delicate manipulation which I call controlled accident – can natural phenomena be incorporated into our own creativity, to yield an image where the reality of a tree confers its truth upon the events we cause to transpire beneath it.” (Deren, 1960.)

Entering a modern scientific research laboratory with this contextual background in mind complicates the delicate conversation between the arts and the sciences right from the outset. With or without realizing it, the modern scientist’s thinking is irrevocably influenced by Richard Dawkins’ *The Blind Watchmaker* (1996), which emphasizes the (presumably) purely objective point of view of scientific observation and the presumed absence of any form of determination in the natural world. Plants, as an object of study, are purely passive and can be freely manipulated for any human purpose. Therefore, a photographic image of a plant is either purely instructive or, alternatively, is no more than a decorative illustration.

However, common ground is much easier to find between the material and processual nature of both the arts and the sciences. Research scientists are interested in processes and visualization techniques that can be used to confirm the manifestation of certain bacteria, viruses, enzymes, or proteins. Common techniques include gel electrophoresis, dot blots, and Elisa plates.

These methods rely upon biochemical reactions that are similar to the reactions that occur in analog photography; there is even an unambiguous overlap in some cases. Visual information is routinely used in order to answer simple yes/no questions or to quantify the occurrence of a certain molecule that is of interest. This type of information is gathered continuously and is reworked in graphs and tables thereafter. Hence, the results of the research undertaken in a laboratory appears in a digital, highly organized format to the outside world. However, the day-to-day work relies on a practice that is not all that far removed from the work done by photographers in a darkroom or by painters who prepare their own pigments.

The residency at St. George's University was an excellent opportunity to compare and contrast the material and processual aspects of my own work in relation to the research done in the lab of Prof. Julian Ma and his group; it was particularly interesting given my background as both a photographer and filmmaker who is interested in alternative photographic processes. In addition to the overlap described previously, a second common interest appeared, namely the plants' proficiency to perform complex tasks. The group's research focuses on the plants' ability to produce enzymes that can be used in novel treatments to prevent and cure diseases, such as HIV and COVID-19. Both common tobacco plants and the closely related *Nicotiana Benthamiana* species are the 'primal helpers' in this astonishing process.

One of my project's most important aims was to gain a further understanding of the lab's workflow. It is significant to mention a fact that might seem very obvious here: the scientists' aim was to develop new treatments and new ways of producing medicines. Tobacco plants are presented and described as biofactories throughout their publications. Research starts from the patient's perspective, by looking at the pathogen that causes disease first. Certain patients develop antibodies that can be isolated in the lab. The biochemical composition of the enzymes in question are then studied and the resulting sequence is amplified and introduced to a bacterial colony. Some bacteria will start to produce the desired enzyme and, after selecting these, the bacterial strain will be introduced to a tobacco plant. This is done through agro-infiltration in which a buffer solution, containing the bacterial strain, is injected into the leaves. The plants that survive this process will start replicating the desired enzymes. Clippings of the plant can also be grown and the product can then be harvested and purified.

Each step of this complex procedure is repeated many times in order to refine and to optimize the process and, subsequently, to breed tobacco plants that perform the task that is assigned to them in the most optimal way.

Researchers carry out a mixture of experiments relating to different stages of the whole process on a typical workday in the lab, thereby resulting in a seemingly chaotic flurry of activities. Tools vary from improvised DIY setups to high-tech equipment. The materials also vary greatly; in addition to the highly specialized products that are produced industrially by specialist companies, researchers also use household products such as milk, salt, and ice. In this process numerous blot plots, gels, and colorimetrics are produced while bottles, plates, vials, plant pots, and even individual leaves need to be labelled in order to keep track of each iteration. The information obtained through these methods is, finally, condensed in graphs and tables in order to be presented at conferences and in journals.

Scientists use frequently used words in addition to the technical terminology that is used in their articles. Genes are 'expressed' in leaf tissue, proteins are 'humanized', and plant lines have 'characteristics'. However, the typical point of view is viewed as both deterministic and the researcher's relationship with the tobacco plants is viewed as utilitarian. This does not mean that the people in question have no feeling toward the objects, processes, and creatures that reside in the lab. In practice, it is common to talk about several aspects of their work in more relational terms. My project's focus has been to look closely at these quotidian areas of scientific practice: everyday visualizations, DIY solutions, ordinary gestures, notations, and evocative vocabulary.

I have explored a number of visualizations using both my own methods and the visualization tools and techniques available in the lab, in close collaboration with the scientists. My own method, phytography, is based on early photographic chemistry and the subsequent renaissance of recipes for plant-based developers that have recently gained widespread attention. By looking closely at such formulae, I hypothesized that it might be possible to use elements of plants in their entirety, instead of extracting their juices. The plant starts releasing polyphenols or terpenoids, molecules that can function as active ingredients in photochemical processes, after soaking leaves, petals, or stems in a deconstructed version of the original formula. Plants make their own image on photographic emulsion by means of this concept.

Firstly, I used mature *Nicotiana tabacum* leaves, preparing these in a Vitamin C and soda solution. The primed leaves were then pressed onto photographic emulsion for several hours. The resulting image shows the structure and chemical make-up of the leaf, but simultaneously has a painterly quality, resembling abstract expressionist paintings. Secondly, I used a similar leaf as an overlay for a photograph of the purifying machine that can be found in the lab. I first exposed a roll of black and white film, taking shots of this intriguing machine. I then developed these images by following the reversal process. Reversal processing is used for slides and certain types of cine-film. I used a primed tobacco leaf instead of using the required second developer. The result is a superimposition, a combination of a camera image and a phytogram, a dreamy, almost surreal image of a sleekly designed technical tool. Next, I used the (much smaller) leaves of 'wild type' *Nicotiana benthamiana* in order to make a phytogram on a laboratory high speed film. Both the film and the leaves are much more delicate, resulting in an image resembling a Chinese Ink drawing. Finally, I photographed a flowering tobacco plant and developed the roll in the juices of this very same plant. After taking the photographs, the flowers were used to make a strong 'tea'. By adding Vitamin C and soda to this liquid, I created a workable photographic developer. The resulting 'self-portrait' has an ominous quality, imbuing the plant with a hitherto undisclosed form of power.

In parallel to this, another set of images was assembled in close collaboration with the scientists working at the lab. These images have been uncoupled from a purely scientific context, allowing for a simultaneously scientific, aesthetic, and symbolic reading. Firstly, I explored dot blot and gel electrophoresis by isolating and enlarging the basic symbols used in these processes. An evocative image emerges by combining both tokens. Secondly, I photographed a stack of Elisa plates in extreme close-up, thereby accentuating the subtle color spectrum and the lens-like quality of the wells. Finally, I looked closely at a number of cryo-electron microscopy images, identifying a pattern in a seemingly random distributed protein swarm. I also took a number of 'traditional' photographs focusing on remarkable objects, tools, and gestures, aiming to hint at the devotion and intensity that is required in this line of work. In this way, the lab suddenly turned into a space filled with sculptures, installations, and performances, simply by allowing for an artistic point of view to be included.

The important point for me is to seek for a shift in possible readings of signs and symbols in both the arts and the sciences. I am interested in advancing a much more relational framework, instead of a utilitarian point of view or the typical dichotomy between the different fields. Visualizations, such as dot blots, gels, and Elisa plates, are not just carriers of scientific data; instead, these techniques are deeply embedded in a cultural framework and can function in various ways beyond a scientific context. Simple gestures, such as watering a plant or injecting that same plant with a fluid containing bacteria, define our ambiguous relationship with these living beings. I propose that tobacco plants are clearly both ingenious and generous. These plants are able to produce complex enzymes almost effortlessly. While the production of a certain molecule would require a very expensive and complex factory in the human world, the plant is able to pull off the same feat with only minimal means. Plants donate their enzymes without protest and can potentially regrow and continue giving. Following this line of thought, the potentiality of tobacco plants is something to consider with awe.

I favor a layered and, therefore, insecure interpretation of the images that I produced. These photographs can be read in multiple ways, including scientific, material, symbolic, metaphorical, and posthuman interpretations. As concisely articulated by the philosopher Rosi Braidotti, our time calls for a point of view that is based on and/and, not either/or (Braidotti, 2019). A simple white dot on a black background can stand for a biochemical signal, a gesture made by the researcher, an expression of quantum mechanical relations, the moon, or even a full stop. The important point is that we recognize that information flows not only between humans, but that our entire environment brims with informational streams, connecting us not only to each other but also to such a complex and lavish creature commonly known as tobacco.

This relatively short exploration is part of an ongoing artistic investigation revolving around biosemiotics (the study of sign aspects in processes of life). The Newcotiana residency has provided me with new insights and has also sparked many new questions. Much remains unanswered and unexplored, bolstering my resolve to explore this line of inquiry further.

# BIBLIOGRAPHY

01. Braidotti, R. (2019). A Theoretical Framework for the Critical Posthumanities. *Theory, Culture & Society 36*, 31-61.
02. Dawkins, R. (1986). *The Blind Watchmaker.* Harlow, Longman.
03. Deren, M. (1960). Cinematography: the Creative Use of Reality. *Visual Arts Today*, Pp. 154-171.
04. Doing, K. (2020). Phytograms: Rebuilding Human–Plant Affiliations. *Animation 15,* 22-36.
05. Schiebinger, L. L. (1996). The Loves of the Plants. *Scientific American 274*(2) 110.
06. Schultz, P. (1998). Robert Mapplethorpe's Flowers. *History of Photography 22*, 84.

# VISUAL ESSAY

by Karel Doing

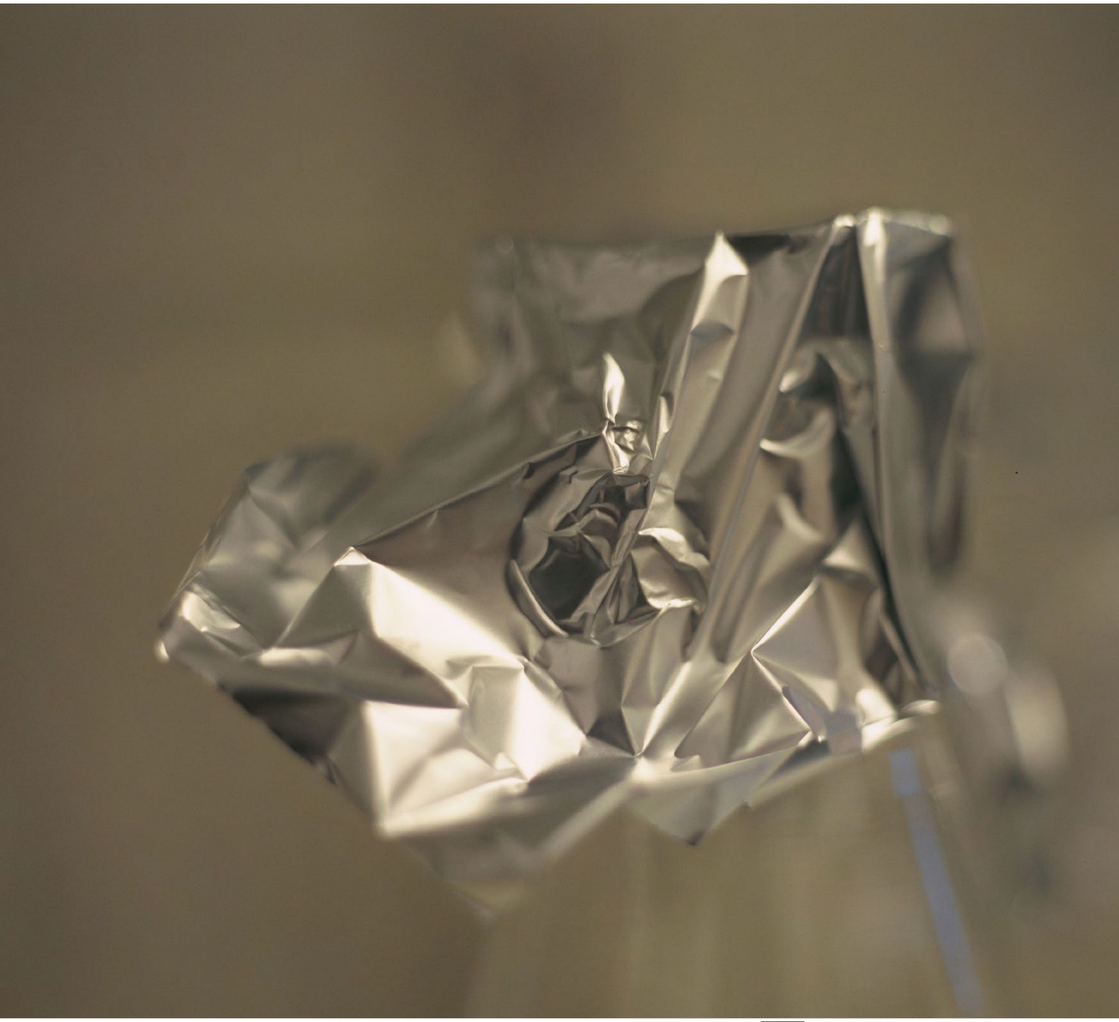
falling in love with your tools

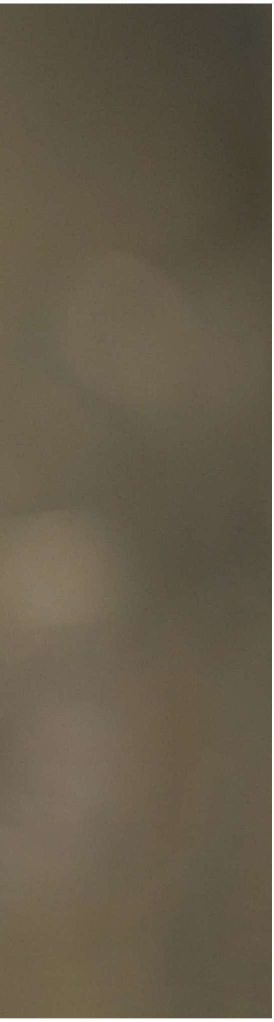
"...THE LAB SUDDENLY TURNED INTO A SPACE FILLED WITH SCULPTURES, INSTALLATIONS, AND PERFORMANCES, SIMPLY BY ALLOWING FOR AN ARTISTIC POINT OF VIEW TO BE INCLUDED."

simple solutions for complex problems

the absence of hands

"I also took a number of 'traditional' photographs focusing on remarkable objects, tools, and gestures, aiming to hint at the devotion and intensity that is required in this line of work."

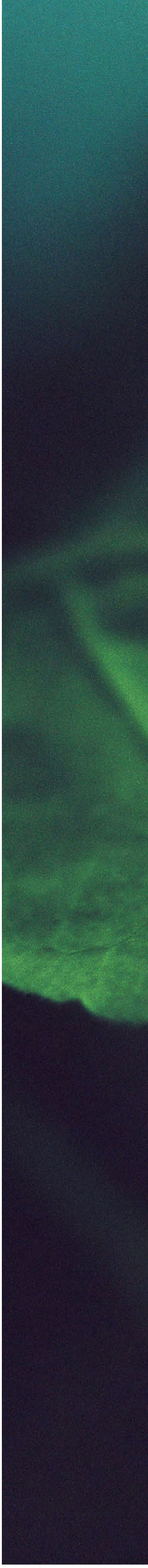




spontaneous sculpture

"SIMPLE GESTURES, SUCH AS WATERING A PLANT OR INJECTING THAT SAME PLANT WITH A FLUID CONTAINING BACTERIA, DEFINE OUR AMBIGUOUS RELATIONSHIP WITH THESE LIVING BEINGS."





quest for a cure

cook, artist, or scientist?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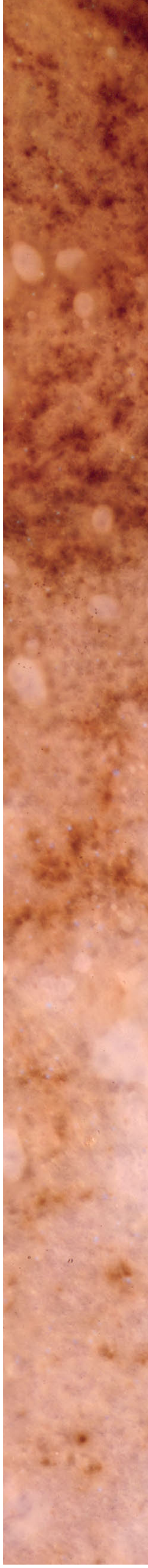
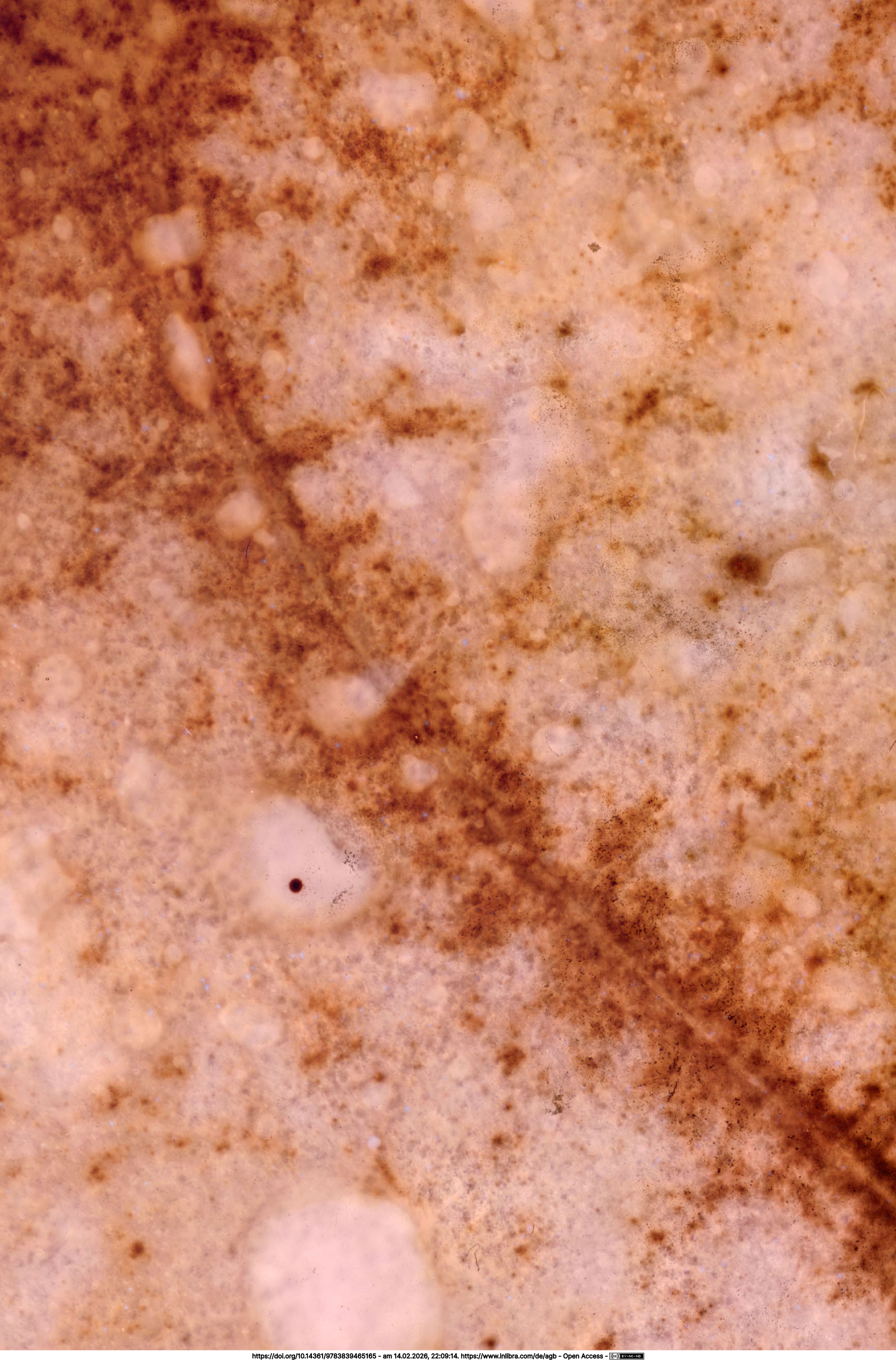
self portrait by *Nicotiana tabacum*

"FINALLY, I PHOTOGRAPHED A FLOWERING TOBACCO PLANT AND DEVELOPED THE ROLL IN THE JUICES OF THIS VERY SAME PLANT. AFTER TAKING THE PHOTOGRAPHS, THE FLOWERS WERE USED TO MAKE A STRONG 'TEA'. BY ADDING VITAMIN C AND SODA TO THIS LIQUID, I CREATED A WORKABLE PHOTOGRAPHIC DEVELOPER. THE RESULTING 'SELF-PORTRAIT' HAS AN OMINOUS QUALITY, IMBUING THE PLANT WITH A HITHERTO UNDISCLOSED FORM OF POWER."

"...I used mature Nicotiana tabacum leaves, preparing these in a vitamin C and soda solution. The primed leaves were then pressed onto photographic emulsion for several hours. The resulting image shows the structure and chemical make-up of the leaf, but simultaneously has a painterly quality, resembling abstract expressionist paintings."



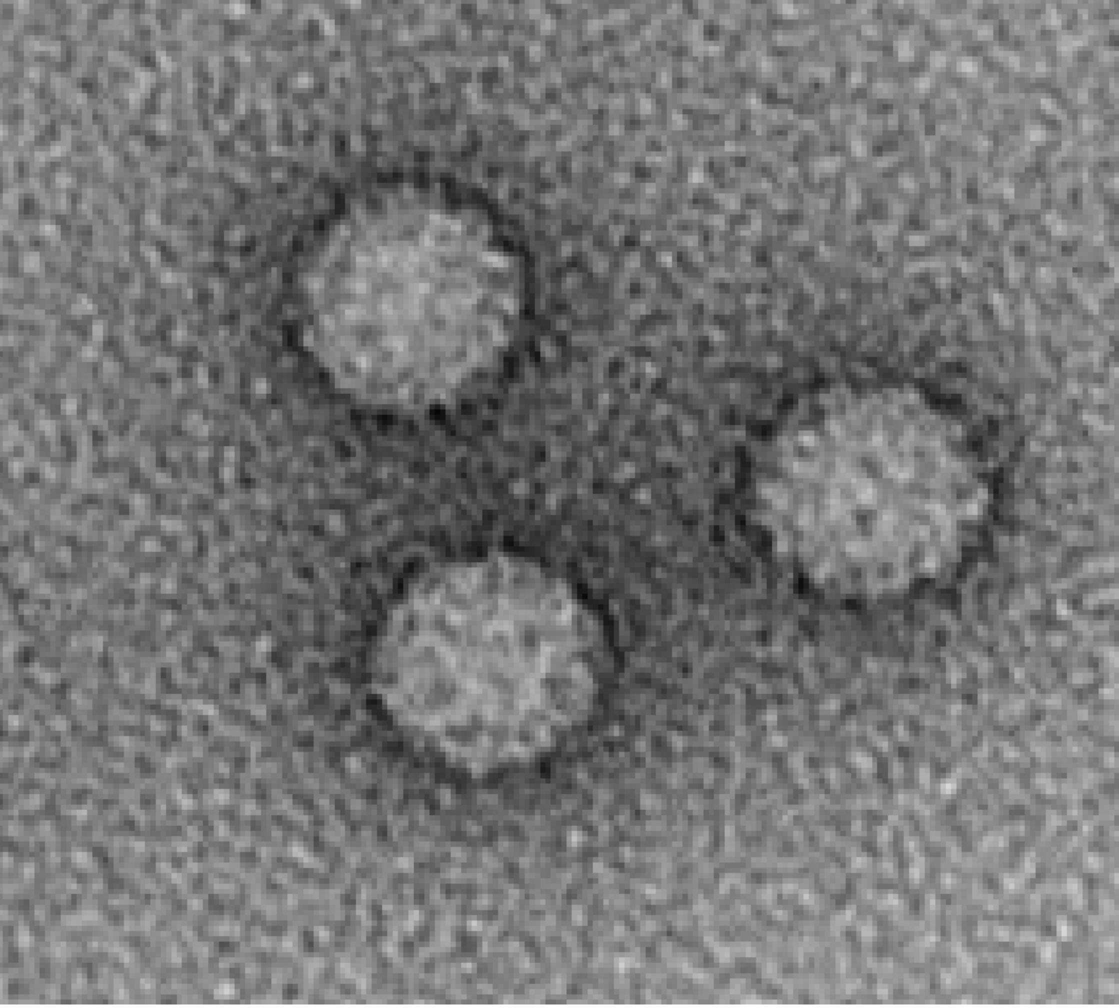
phytography revealing the vein of a leaf



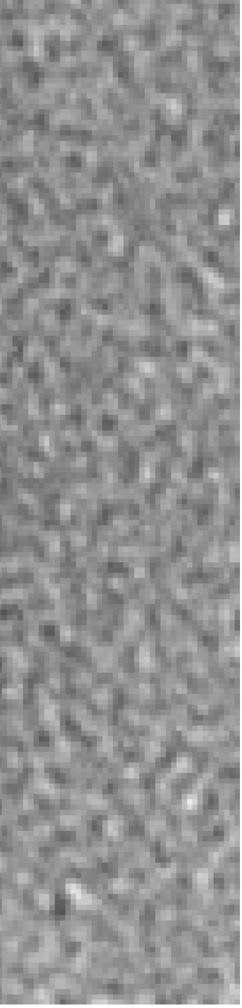

20% EtOH
ÄKTA pure

"I USED A PRIMED TOBACCO LEAF INSTEAD OF USING THE REQUIRED SECOND DEVELOPER. THE RESULT IS A SUPERIMPOSITION, A COMBINATION OF A CAMERA IMAGE AND A PHYTOGRAM, A DREAMY, ALMOST SURREAL IMAGE OF A SLEEKLY DESIGNED TECHNICAL TOOL."

plate washer with droplet reflecting the lab



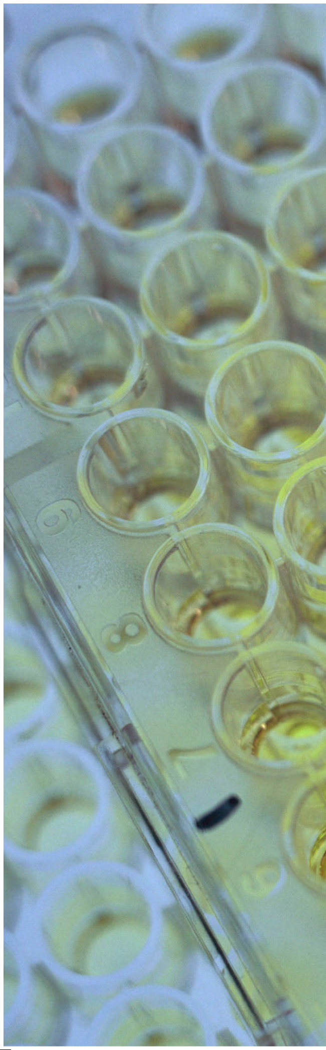
"...I LOOKED CLOSELY AT A NUMBER OF CRYO-ELECTRON MICROSCOPY IMAGES, IDENTIFYING A PATTERN IN A SEEMINGLY RANDOM DIS-TRIBUTED PROTEIN SWARM."

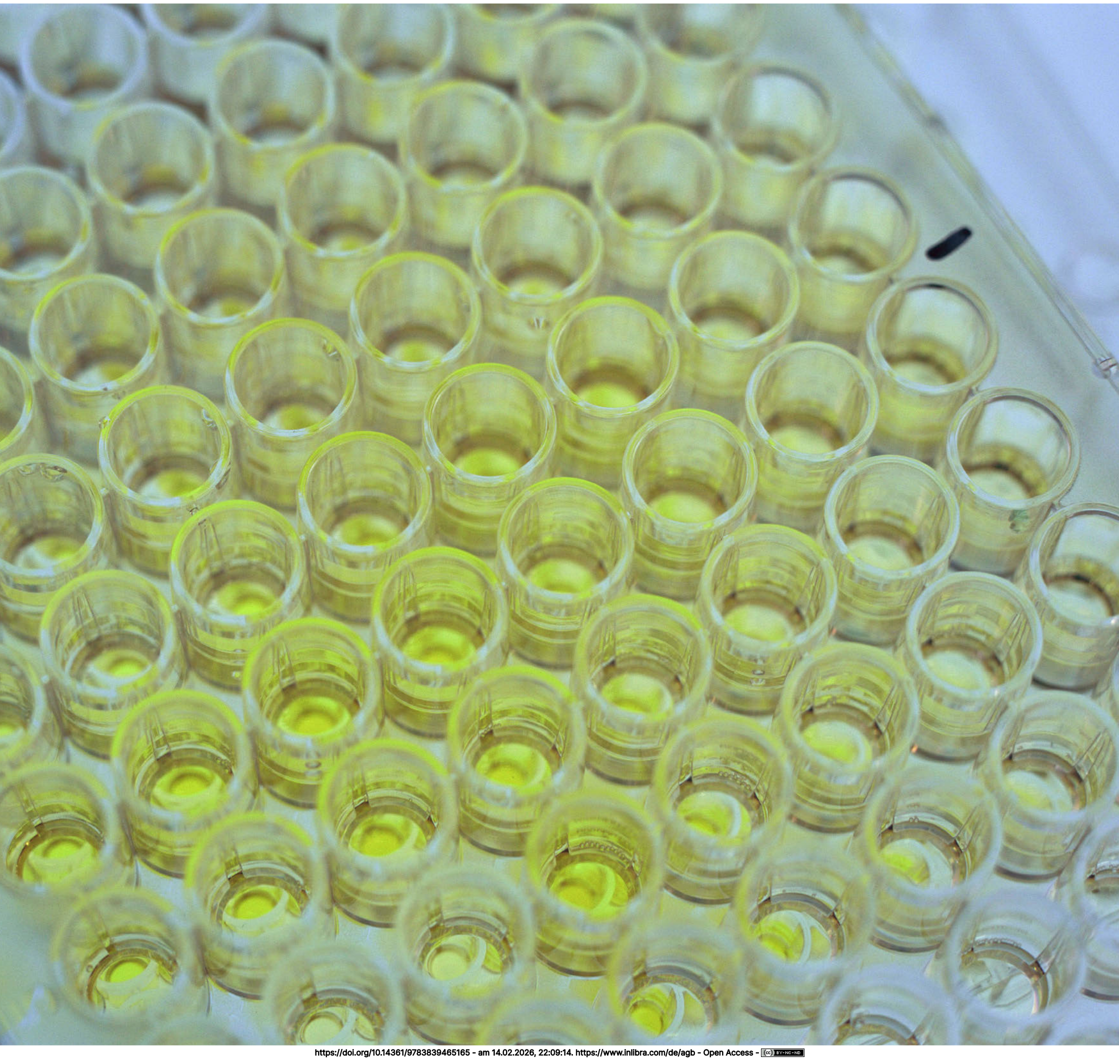


pareidolia in cryo-electron microscopy

"…I EXPLORED DOT BLOT AND GEL ELEC-TROPHORESIS BY ISOLATING AND ENLARGING THE BASIC SYMBOLS USED IN THESE PROCESSES. AN EVOCATIVE IMAGE EMERGES BY COMBIN-ING BOTH TOKENS."

sunrise on a stack of Elisa plates





"...I USED THE (MUCH SMALLER) LEAVES OF 'WILD TYPE' NICOTIANA BENTHAMIANA IN ORDER TO MAKE A PHYTOGRAM ON A LABORATORY HIGH SPEED FILM. BOTH THE FILM AND THE LEAVES ARE MUCH MORE DELI-CATE, RESULTING IN AN IMAGE RESEMBLING A CHINESE INK DRAWING."

# TOBACCO RESEARCH THROUGH DIFFERENT LENSES: REFLECTIONS ON THE INFLUENCES OF ART IN SCIENCE

by Cathy Moore, Kathrin Göritzer & Julian Ma

The opportunity to discuss one's scientific research with someone outside of the field of science is a privilege that should never be missed and is rarely without value. Being able to describe your work, your motivation, and your goals clearly and understandably is a skill that is overlooked too commonly, but it is just as important to accept the feedback, identify areas in which you have not made yourself clear, and to view your passion from someone else's perspective. Some scientists are good at 'public engagement in science', but no one has nothing left to learn, because the 'public' is almost infinite in its experience and diversity, and every engagement is different.

In this chapter, we first describe the overall view held by research group lead, Prof. Julian Ma, and then provide insights from two early career researchers Dr. Kathrin Göritzer and Dr. Cathy Moore, who worked with Karel Doing during his residency on a day-to-day basis.

**Overview by Prof. Julian Ma**

When the opportunity arose to host an artist-in-residence, I registered my interest immediately. As a Professor of Molecular Immunology at St. George's, University of London, I lead a research group of around 15 scientists at different stages of their career, from post-graduate students to early and mid-career researchers. We run a variety of public engagement in science events, from school visits to informal talks to the University of the 3rd Age[1],

[1] It is an organization that allows local groups to form for people no longer in work to meet and invite speakers. For more info, you can visit: https://www.u3a.org.uk/.

from a monthly science club in our local prison to workshops for young students in Bangkok. However, the opportunity to host an artist-in-residence was something quite different and was too good an opportunity to miss. Having an artist working alongside us for an extended period of time, and integrating themselves into the research group, would give us an unprecedented opportunity to share our world and to see our work from completely new angles. Our research group has little or no artistic experience. A couple of us are enthusiastic amateur musicians and one has a background in interpretive dance, but no one has expertise in the visual arts.

An additional motivation was that our area of research has skated the edge of controversy for many years, and our research community's previous failures to engage pro-actively with the public has resulted in a loss of trust and a stalling of our work's progress. We work in plant biotechnology and use genetic modification (GM) and gene engineering. In our case, our goal is to use plants to manufacture modern medicines – antibodies and vaccines – against infectious diseases, particularly those common in lower- and middle-income countries. Since the start of the millennium, though, our research has been entangled with a public fear of GM, as well as our use of tobacco as our plant of choice as a manufacturing platform. The EU-funded Newcotiana project, which provided the opportunity for Karel Doing to work with us, is actually a multi-national project designed to illustrate the potential benefits of plant biotechnology, and our role in that project was to develop better plants for making medicines and to provide examples of the kinds of drug products that plant biotechnology might enable.

Karel joined the laboratory at an advanced stage of the Newcotiana project, when we had already made some important advances and were at the stage of trying to show examples of the benefits that our work with plants could deliver. It was also at the point at which we were only just able to open up our laboratories, following COVID-19 lockdown, during which time our research had, out of necessity, pivoted almost entirely to COVID-19 research. We agreed, however, that we would not necessarily focus on particular medicinal products in our discussions with Karel, but would instead concentrate on the bigger picture, the concept of molecular pharming (using plants for manufacturing modern medicines), and on our relationship with plants.

The residency itself was scheduled around COVID-19 restrictions and travel difficulties between Karel's home in Oxford and St. George's, which is in South-West London. The key achievement was to have Karel spend an extended period working alongside and shadowing members of the laboratory, particularly two experienced postdoctoral scientists, Kathrin Göritzer and Cathy Moore. One of the highlights for me was the genuine interest and fascination that Karel showed for the scientific techniques that we use, many of which, are routine and of no great novelty for us. It was a revelation to observe an adult's reaction to science in action. Not afraid of asking questions, Karel explored both complex and fundamental issues, which challenged all of us to find ways to explain concepts that we usually take for granted.

Due to the COVID-19 restrictions, the residency did not progress as planned; there was an element of stop-start to our working together, but that was actually beneficial in retrospect and it gave Karel a chance to digest information, and the research team a chance to re-evaluate how we engaged with him. There were no significant lows, except for one important learning point. Towards the end of the residency, when Karel sent us his draft output, we were all disoriented by the abstract nature of his images and descriptions. Unlike any output that we were familiar with from the scientific world, our immediate reaction was that we had not explained our work adequately or conveyed our passion for our scientific objectives, and we were surprised and perhaps a little disappointed that Karel had focused on what, to us, appeared to be more mundane everyday matters of process. It was only with time that we realized that this represents one of the project's most important outcomes.

It is easy to talk in lofty terms about public engagement in science – why it is needed and what the benefits are. We also discuss the importance of feedback and spend much effort designing approaches to retrieving relevant feedback. A major limitation of conventional feedback, though, is that its nature is largely determined by the questions asked. In this project, Karel's photo essay is the most original, non-directed type of feedback that I have received. It has made me re-think the nature and objective of engagement in science. Why should a scientist expect a member of the public to find the same areas to be fascinating in the same manner as those who are working in the field? Perhaps it is even presumptuous to overlook that scientists approach their work in a particular way, that others may find more interesting things or elements than the work itself. The procedures that we perform day-to-day become routine, but they are amazing to those who are not familiar with laboratory science. This, of course, speaks to the essence of engagement, that of a two-way process, in which engagers learn equally from the process as engagees.

An appreciation of the visual arts perhaps works similarly. When we visit an art gallery, we are not usually inundated with descriptions of the background, the methodology, the interpretation, or the significance of the art.

Instead, there is usually a paucity of information, and we are left to identify what we individually find most appealing and memorable.

Karel's perspective on our use of plants as tools is both new and revelatory. His vocabulary is different and the insight he gained into our world was unexpected. This residency has not just established new friendships, but it has also changed my future approach to public engagement in science.

**Insights by Dr. Kathrin Göritzer and Dr. Cathy Moore**
**New perspectives**

Scientists are famously myopic and struggle to see the forest for the trees. Having an artist-in-residence pushed us to step back and to view what we do from a fresh perspective. Initially, trying to explain concepts that we take for granted that the bubble around us already know was frustrating; however, it helped us to remove ourselves from this strict mindset and we learned how to explain our work to a layperson, which is an important skill for scientists pursuing public engagement. Beyond merely taking a step back from our own work, we were forced to view our work from the artist's viewpoint which was challenging, but we needed to do it in order to understand the concept of free interpretation. So constrained are we to the idea that accuracy is everything that it was quite jarring to adjust to the idea of artistically interpreting our work such that aesthetics and emotions, rather than accuracy and facts, take precedence.

Ultimately, it was quite satisfying to induce such enthusiasm for our work from a layperson. We are generally a link in a long chain, from bench science to healthcare application, as research scientists and we rarely get to see any appreciation for the work that we do. As such, it gave us a sense of pride to see a member of the public so enamored with our day-to-day efforts.

In several instances, we were analyzing our results from an experiment, or using a routine piece of equipment, and this would spark a reaction from the artist that surprised us. Our mindset in science trains us to see no value in an experiment's background noise and we barely acknowledge the tools by which we perform our experiments. Familiarity and failure are both instruments of neglect. Imagine our surprise, then, when the artist wanted to take pictures of a plate-washer, or a failed experiment, for no other reason than the objective aesthetic of it. For him there was no sense of either failure or familiarity. Therefore, he could see the beauty of it and, through him, we could too.

## Out of the comfort zone

The collaboration was initially quite laborious as we were almost having to think aloud, explaining everything we were doing. Normally, when we have people shadow us in the lab, they are science students who have a general understanding of the core underlying principles of what we are doing. In this case, the artist had no scientific background at all and this made explaining our actions more difficult. However, it turned out to be very instructive. It gave us the opportunity to learn how to articulate our work to the general public and highlighted the sort of scientific language that puts the public ill at ease about our field. It was satisfying to see the recognition of not only the process, but the ultimate purpose and what it achieves.

Along these same lines, it was very interesting to learn how differently scientists and artists approach things. It could be said that scientists pursue quite a binary approach: did it work, yes or no? Is the equipment fit for my purposes, yes or no? From the artists' perspective, everything had some aesthetic value and the constraints for value were not a hard border, but rather a spectrum.

Another unusual aspect to having an artist in the lab was being on camera, rather than being obscured behind the work itself. In science, the work itself is always the focus, be it a research paper or a new device or treatment, but the scientist is usually in the background. For the most part, scientists are quite comfortable with this arrangement, as we are stereotypically a reticent bunch, so suddenly findings ourselves in the spotlight pulled us out of our comfort zone.

## Learnings

As scientists we, of course, liked the way Karel used plant juices to develop photos of the plant. Our group already uses tobacco in a non-conservative way by having them produce medicines, rather than causing harm; we are trying to make them a global healer, instead of a global killer. The idea that these plants could even be used for something as benign as a photography developing agent is very much within our scope.

Furthermore, it was eye-opening to appreciate the aesthetics of objects that we see every day, but not that many people take the time to appreciate these objects. Both the process of residency and the artwork that came out of it brought us many new learnings. We learned about the juxtaposition between science and art, despite the societally accepted friction. The experience was very helpful for us in training us how to explain our work to laypeople. It also ignited our own excitement about our work and our medium by seeing it through fresh eyes. As scientists, it is not our main purpose to provoke an emotional response, but rather to disseminate knowledge; however, through this experience we learned that such emotional responses should not be dismissed entirely and could even be valuable.

In other words, we learned that there is a place for art in science.

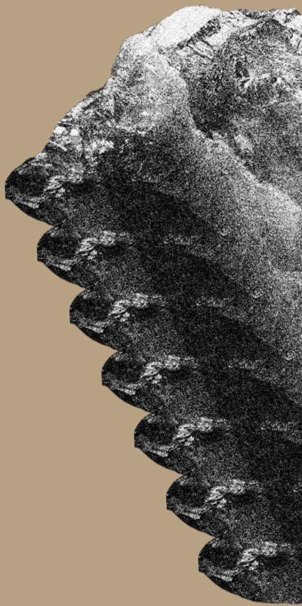
SINFONIA

*Sinfonia has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 814418.*

# SINFONIA

Materials containing the element fluorine (F) are extremely important and have applications in electronics, healthcare, the automotive sector, and wearables. These materials are currently exclusively synthesized using chemical methods, thereby leading to toxic production processes that have negative impacts on the environment and on people.

SinFonia wants to change the way that fluorine is produced by using synthetic biology. The project develops ways to generate novel fluorine production methods that use renewable substrates. The project's scientists aim to design alternative sustainable bioprocesses for fluorine production by engineering the metabolically versatile bacterium *Pseudomonas putida* to execute bio-fluorination.



# PABLO IVAN NIKEL – THE NOVO NORDISK FOUNDATION CENTER FOR BIOSUSTAINABILITY

The Novo Nordisk Foundation Center for Biosustainability (DTU Biosustain) at the Technical University of Denmark aims at developing new knowledge and technologies to help facilitate the transformation from the existing oil-based chemical industry to a more sustainable bio-based society in which chemicals are produced biologically.

# EDUARDO MIRANDA

Eduardo Reck Miranda is a composer and AI scientist working at the crossroads of music and science. His interdisciplinary work and research contribute to the advancement of scientific knowledge of AI, neurotechnology, and unconventional computing. He is also a professor of Computer Music at the University of Plymouth.

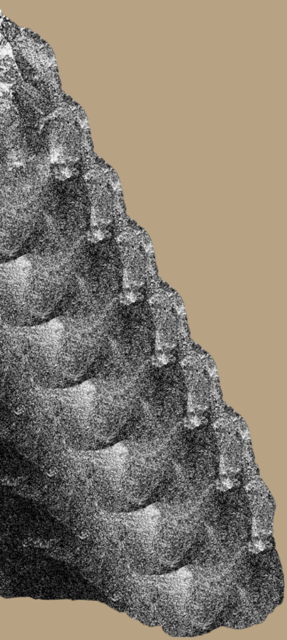


fig. 2.1 In nature, fluorine will often be found in minerals such as fluorite. Fluorine is the most abundant halogen on Earth and is an integral component of many modern materials. It is used both in industry and in everyday life.

# MAKING MUSIC WITH ENZYMES

by Eduardo Reck Miranda

My residency took place in the context of the research developed by partners based at the Technical University of Denmark. I interacted with Pablo Iván Nikel and his team of scientists, including Manuel José N. Domíngues and Nicolas Krink, at the Novo Nordisk Foundation Center for Biosustainability. These scientists helped me to understand the SinFonia project's challenges and how the consortium has tried to tackle them. The interactions with these scientists prompted me to become introspective about my creative process. To my mind, as a musician with a scientific background, the distinction between composing a symphony and conducting a scientific experiment is somewhat blurred; I also realize that this is not necessarily the case for all artists and scientists.

In this chapter, I will discuss my process when it comes to composing music and will articulate the role played by science in my creative process. I will unpack why working at the intersection of art and science is so interesting to me. I will then present the pieces of electronic music that I composed during my residency, as well as their background story and the system that I designed to make music with DNA codes.

I often find myself confronting the following dichotomy when I introspect my compositional practice: on the one hand, I think of music as the intuitive expression of ineffable thoughts, highly personal impressions of the world around me, and as the irrational manifestation of emotions. On the other hand, I am keen to maintain that music should be logical, systematic, and should follow guiding rules. In general, I think that rationality plays an important role in music composition, especially in classical music. It is definitely prominent when I develop art-science interdisciplinary projects.

Any attempt to distinguish the rational from the irrational in musical composition ought to take the scientific developments, and above all the music technology, of the time into account. The most influential music technology of our time is undoubtedly the computer: it is a general-purpose device that can be programmed to carry out musical tasks such as, for example, generating music following sets of arithmetic and logical operations. One of computers' most important benefits is that they facilitate musical composition, informed by processes and data abstracted from phenomena other than music; for example, these can include meteorologic, hydrologic, and genetic data, respectively.

The use of computers to generate original musical compositions dates back to the mid-1950s. In 1956, Lejaren Hiller composed *The Illiac Suite for String Quartet*, which was allegedly the first composition to contain computer-generated materials. Hiller teamed up with Leonard Isaacson to program the mainframe computer ILLIAC at the University of Illinois in the USA to generate music by following rules. The computer produced music using both the rules of counterpoint and a technique known as Markov chains to generate sequences of patterns. The computer's output was transcribed manually into standard musical notation on a score to be played by a string quartet.

I use the computer to generate materials for my compositions regularly. These materials include riffs, sequences, rhythms, melodies, entire sections lasting for several minutes, and indeed synthesized sounds. More often than not, musical form emerges as I work with the compositional materials at hand. To begin with, I tend to not have an overarching plan for the form my pieces end up taking. The compositions emerge from the handling of the materials that I am working with to compose a particular piece.

For the most part, my computer-generated materials are discarded, and I usually amend certain selected ones in order to fit particular compositional contexts, aims, and so on. Ultimately, it is my ear that has the final say. However, this compositional process's dynamics beg further understanding. I often find myself asking why I find working with computer-generated materials exciting. If I discard most of the materials generated by the computer, and often edit those that I select for a particular piece, then why do I not write these materials myself instead?

One of the reasons that I find working with computers exciting is because they can generate musical materials that I would not have been able to produce on my own manually. This mindset is akin to John Cage's thinking when he preferred to set up the conditions for music to happen, rather than composing music set in stone. Cage liked being surprised by the outcomes of such happenings (Cage, 1994). By the same token, I enjoy being surprised by the outcomes of a computer.

Technically, there are two approaches to designing computer systems to generate music, which I refer to as 'Artificial Intelligence' (or AI) and 'algorithmic' approaches, respectively.

The AI approach is concerned with embedding the system with musical knowledge to guide the generative process. For instance, computers have been programmed with rules of common practice for counterpoint in order to generate polyphonic music (Jacobs & Regia, 2011). Machine-learning technology has enabled computers to learn musical rules automatically from given scores, which are subsequently used in order to generate music. Conversely, the algorithmic approach is concerned with translating data that is generated from (seemingly unmusical) models onto music. Examples of this approach abound; for instance, computers have been programmed to generate music from chaotic functions (Dabby, 1996), fractals (Dodge, 1998), and, indeed, even DNA (Miranda, 2020). My work on generating music with DNA is discussed in greater detail below.

Aesthetically, the algorithmic approach tends to generate highly novel and unusual music, whereas the AI approach tends to generate imitations of certain types of music that exist already. Both approaches have their own merits and pitfalls. Even though I strive to combine both, I often adopt the algorithmic one; I adopted the algorithmic approach to compose the pieces for my SinFonia residency. However, before I describe the residency work, it is important to first spell out how I use computer-generated materials in my work.

There are two approaches to composing with computer-generated materials which I refer to as the 'purist' and 'utilitarian' approaches, respectively. The purist approach to computer-generated music tends to be more concerned with the correct application of the rules that are programmed in the system, than with the musical results per se. In this case, the computer's output tends to be considered as the final composition. That is, in this case, the composer would not normally modify the materials produced by the computer. It is thought that this would meddle with either the model or system's integrity.

The utilitarian approach can be found at the other end of the spectrum. This is the approach adopted by those who consider the output from the computer as raw materials for further work. In this case, composers normally tweak the results to fit their aesthetic preferences, to the extent that the system's output might not even be easily identifiable in the final composition. Obviously, there is a blurred line dividing these two approaches, but practices combining aspects of both abound.

The computer's role in my compositions has oscillated between two extremes: on the one hand, I have simply assumed the authorship of compositions that were entirely generated by a computer, but which were programmed to follow my exact instructions. On the other hand, I have composed with pencil on stave paper, using the computer only to typeset the final score. I shall argue that both approaches to composition are not incompatible; rather, they are manifestations of creative processes that are becoming progressively more polarized due to technology's increasing sophistication. Let us unpack this further.

First, I should mention that I have become increasingly less interested in the purist approach as my career has progressed. Indeed, the exciting computer music challenge of the 20th century is over. People questioned whether computers would be able to compose music with the development of AI towards the end of the last century and there were various attempts at formulating criteria to address a so-called "musical Turing test" (Begum et al., 1998). It is now abundantly apparent that computers can be programmed to compose music of a reasonably convincing technical quality automatically. I have been developing systems to do this over the past twenty years and other colleagues have done likewise. Paradoxically, the news media continues to periodically report that, yet again, someone has built a system that can compose music; this is no longer a novelty.

The caveat with computer-composed music is that technical quality *per se* does not necessarily make a piece of music compelling. Music needs to be embedded in cultural and emotionally meaningful contexts which composers express in subtle, often ineffable ways. A computer would not be capable of composing a piece such as Tchaikovsky's *1812 Overture*. Its backstory, myriad of references, drama, and so on are aspects of musicianship that computers, as we know them today, cannot grasp.

One thread that I am currently contemplating, to unravel the role played by the computer in my own compositional practice, explores an idea suggested by philosopher Friedrich Nietzsche ([1872]1993). In a nutshell, Nietzsche suggested that great artistic creations could only result from the articulation of a mythological dichotomy referred to as the Apollonian and Dionysian.

Apollo is the god of the sun and is associated with rational and logical thinking, self-control, and order in ancient Greek mythology. Conversely, Dionysus is the god of wine and is associated with irrationalism, intuition, passion, and anarchy. These two gods represent two conflicting creative drives, constantly stimulating and provoking one another. As I understand it, Nietzsche proposed that this (metaphorical) mythological process would lead to increasingly high levels of artistic and scientific achievement. This approach to creativity resonates with the way in which my creative mind seems to work: One side of me is methodical and objective, keen to use automatically generated music, computer systems, formalisms, and models. For instance, I have developed systems to generate music using Cellular Automata, Genetic Algorithms, grammars, and simulations of biological cells. Conversely, another side of me is anarchic, intuitive, and metaphorical, and I often feel that one side tends to counter the other while I am composing: the more I swing to my Apollonian side, the stronger the Dionysian force that pulls me to the opposite side becomes, and vice-versa. These push-and-pull dynamics transpire most prominently in my mind when I develop interdisciplinary projects with scientists. The SinFonia residency work was no exception in this respect.

McGilchrist (2009) discussed the 19th century Apollonian versus Dionysian dichotomy in the context of 21st century Neuroscience. He aligns this dichotomy with the notion of 'brain asymmetry' (Davidson, 1996; Springer & Deutsch, 1998; Hugdahl & Westerhausen, 2010). In broad strokes, one could consider that specific brain functions tend to be more Apollonian or Dionysian than others. Indeed, several attempts have been made to associate areas of the brain with such functions, but these associations remain largely elusive. Nevertheless, they are useful as working tools for discussion. For instance, the Apollonian brain might involve the frontal lobe of the cortex and the left hemisphere. Generally, these areas are known to be in charge of focusing attention to detail, seeing wholes in terms of their constituents, and making abstractions; they are systematic and logical.

The Dionysian brain might include sub-cortical areas, which are much older in the evolutionary timeline, and the right hemisphere. These areas are connected to our emotions. The right hemisphere tends to perceive the world holistically, leading towards unfocused general views. The Dionysian brain tends to forge connections between allegedly unrelated concepts, while the Apollonian brain is concerned with unilateral meanings. The notion that the Apollonian and the Dionysian brains tend to counter each other is reminiscent of the way in which the brain functions at all levels. Inhibitory processes pervade our brain's functioning, from the microscopic level of neurons communicating with one another to the macroscopic level of interaction between larger networks of millions of neurons.

Hence, formalisms, rules, schemes, methods, number crunching, computing, and so on, are of the utmost importance for my *métier*: They enable me to stretch my Apollonian musical side far beyond my ability to do so by hand, thereby prompting my Dionysian side to counteract accordingly. I would say that this cognitive push-and-pull is a vital driving force behind my musical creativity. Interdisciplinary projects, involving residencies in scientific research laboratories and collaborations with scientists, thus harness my Apollonian-Dionysian push-and-pull. I should say that this is not as clear as I am trying to convey here, however. I tend to get excited about the science that I encounter in these labs and often invest a lot of my time learning the details. It is not uncommon for me to want to contribute to the scientific endeavor as well. One example of this is my work with Brain-Computer Interfaces (BCI). What started as a wish to compose music with brainwaves 20 years ago, ended up being a long research endeavor to understand how the brain processes music (Daly et al., 2020)and to develop BCI technology to enable severely motor-impaired people to make music (Miranda & Castet, 2014).

The remit of my SinFonia residency was to create a composition informed and inspired by a metabolic process referred to as bio-fluorination, which produces fluorochemicals. Fluorine is an important chemical element for our modern world, and so are fluorochemicals – i.e., chemicals that contain fluorine. They are used in manufacturing industries as diverse as electronics, fashion, and medicine. Currently, fluorochemicals are made using chemical processes. However, these are deemed to be of limited capacity to discover new compounds. Moreover, those chemical processes pollute the environment significantly when produced on an industrial scale. SinFonia's ambition is to change this by way of synthetic biology. The project is interested in developing ways to harness the genetic make-up of bacteria[1] in order to make them synthesize fluorochemicals for us.

As a starting point, I wanted to learn as much as possible about fluorochemicals and how they can be synthesized. I could not possibly start composing before satiating my Apollonian side with as much scientific knowledge as I could absorb about Nikel's lab work. The lab was genetically enhancing bacteria to synthesize these compounds and I found this to be inspiring. The techniques that are being developed for synthesizing compounds reminded me of the techniques that electronic musicians use to synthesize sounds. In the same way that chemical components react and combine to form new ones, sinewaves are carefully added together to form new sounds and filters are applied to transform sounds.

[1] SinFonia is engineering the bacterium *Pseudomonas putida* to execute bio-fluorinations.

Broadly, I learned how the team was developing methods to alter the genetic information of the bacterium *Pseudomonas putida* to synthesize new types of fluorochemicals. One approach to doing this was to steer the organism to produce the enzymes needed to carry out a sequence of metabolic reactions,[2] which would ultimately result in a useful fluorochemical called fluoroacetate. This reaction sequence is shown in Figure 2.2. Five metabolites are produced from fluoride's initial reaction with the enzyme S-Adenosyl methionine (or SAM), before ending up with fluoroacetate; these are named as follows:

FDA (5'-fluoro-5'-deoxyadenosine)
FDR (5'-fluoro-5'-deoxy-D-ribose)
FDRP (5'-fluoro-5'-deoxy-D-ribose-1-phosphate)
5-FDRibulP (5'-fluoro-5'-deoxy-D-ribulose-1-phosphate)
Fluoroacetaldehyde

The enzymes required to carry out the metabolic reactions, depicted in Figure 2.2, are Fluorinase, Nucleosidase, Kinase, Isomerase, Aldolase, and Aldehyde dehydrogenase. My Dionysian side began to connect concepts when Manuel handed me those enzymes' DNA codes. Having composed with DNA sequences before, I was keen to customize and improve the generative music method that I had developed for the previous project. I ended up developing a new system: the "Genetic Musinator System".

[2] That is, life-sustaining chemical reactions that take place inside an organism to generate energy.

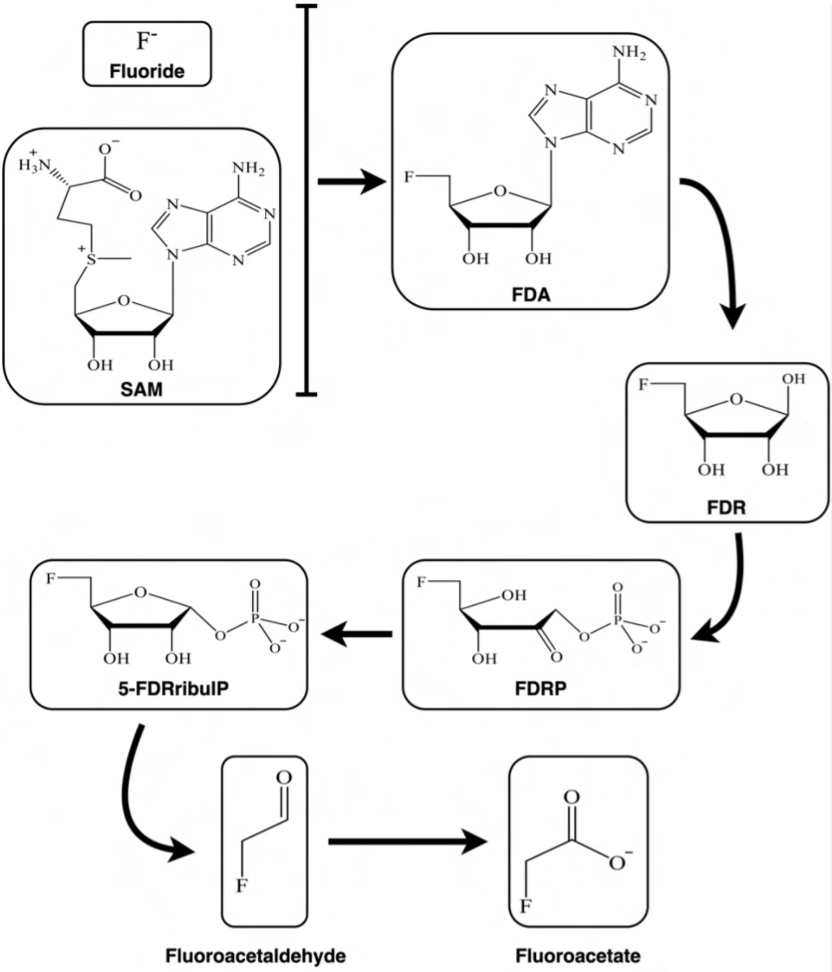



fig. 2.2 Fluoride's initial reaction with the enzyme SAM provides a substrate for metabolic reactions, producing the fluorochemical Fluoroacetate.

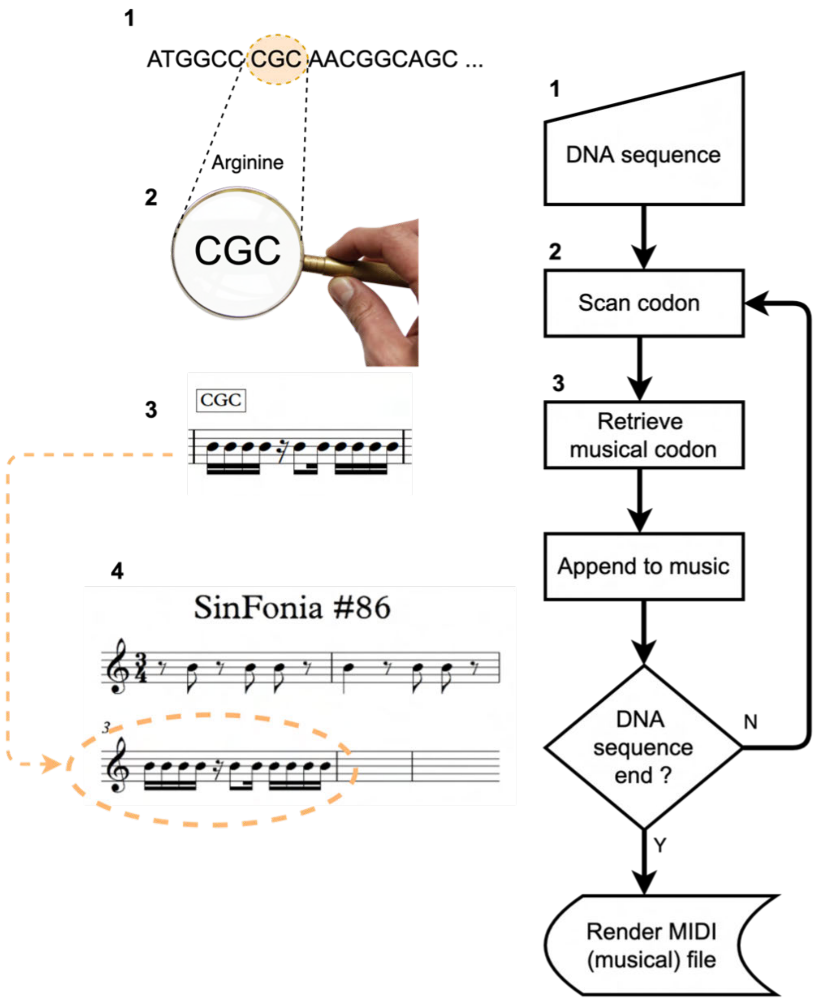



fig. 2.3 The Genetic Musinator System flowchart.

In a nutshell, the system scans a given DNA strand and (a) generates variations of the strands and (b) translates the codons[3] of the original strand, and variations thereof, into musical sequences. The system uses lexicons of musical codons in order to translate the codons into music. I designed twelve different lexicons for this. For instance, in Figure 2.3, as the system scans a given DNA strand, it identifies the codon CGC, which corresponds to the amino acid Arginine. However, the amino acid's name does not matter here. Instead, the system uses this code to retrieve a 'musical codon' from a lexicon (Figure 2.3, step 3). The system then appends this to the musical sequence that is currently being generated for the respective DNA strand.

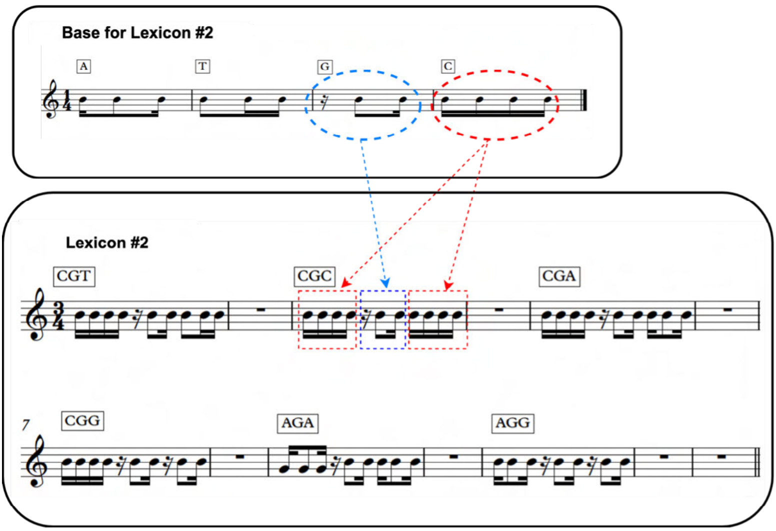



fig 2.4 An example of a lexicon's nucleo-rhythms (top) and an excerpt of the lexicon.

[3] A codon is a triplet of nucleotides representing the DNA or RNA of an amino acid. For instance, the amino acid Methionine is presented by the codon ATG.

The base for each lexicon comprises four 'nucleo-rhythms', each of which represents a DNA (or RNA) nucleotide, A (Adenine), G (Guanine), C (Cytosine), or T (Thymine) (or U, for Uracil in RNA). For instance, Figure 2.4 depicts the nucleo-rhythms for Lexicon #2 (top) and an excerpt of the lexicon (bottom). Each lexicon contains 64 musical codons.

The sequence of reactions shown in Figure 2.2 served as, and generated, inspiration for the composition. To me, the chain of reactions from fluoride and SAM, which ended up with fluoroacetate, resembles a storyline the protagonists of which are chemical elements and compounds. This reminded me of how composers forge musical discourses through the articulation of musical elements (notes, motifs, etc.) and musical compounds (tunes, melodies, etc.). I then envisaged a composition whereby musical representations of the enzymes involved in the chemical reactions, shown in Figure 2.2, are articulated to tell a metaphorical story: the story of fluoroacetate.

Firstly, I generated six individual short compositions, one for each enzyme: Fluorinase, Nucleosidase, Kinase, Isomerase, Aldolase, and Aldehyde dehydrogenase, respectively. I did this by inputting the DNA codes for each of the enzymes into the "Genetic Musinator System". The system generated sets of MIDI files, its automatically generated variations corresponding to the respective original DNA strand. Each of these was considered to be an individual musical track. The tracks were uploaded into a "Digital Audio Workstation" (DAW)[4] and mixed to generate the respective compositions. At this stage, my Apollonian side refrained from editing the tracks produced by the system, but my Dionysian side chose the timbres and selected the tracks to be included in the mix; not all variations were used.

I unleashed my Dionysian side once the 'enzyme' pieces were completed. I uploaded all of the tracks into a musical processor and freely composed them into a larger musical structure. Think of a DAW as the musical equivalent of a word processor. In the same way that one uses a word processor to write words, form sentences, copy and paste phrases and paragraphs, a musical processor enables me to work with 'musical words', 'musical sentences', and 'musical paragraphs'.

The final composition tells a metaphorical story, whereby the six enzyme pieces were deconstructed and their elements (i.e., tracks) were combined

[4] A "Digital Audio Workstation" (DAW) is a piece of software used for recording, editing, and producing music.

and re-combined to represent the process of bio-fluorination. The order of appearance and combinations were dictated by aesthetic preferences purely; that is, by purely Dionysian impulses. The piece begins with tracks from Nucleosidase, and then Aldehyde dehydrogenase enters the scene. A new ingredient appears in the mix as these two 'react': Aldolase. These three musical enzymes somehow make room for the appearance of Isomerase. Subsequently, Kinase emerges. Finally, the Fluorinase enters the scene in order to consolidate the composition and is accompanied by a soothing piano melody.

The team at Novo Nordisk Foundation Center for Biosustainability were just fantastic at patiently explaining what they were doing. It certainly helped the interaction that all of them love music and are amateur musicians themselves. Affinity, respect, and open-mindedness are *sine qua non* for creative art-science projects' success, in my experience. All parties need to understand the respective methodologies, objectives, and materials of the respective fields; that is, music, biology, and chemistry. I feel that we all strived in order to achieve this.

The SinFonia residency left me with an appetite to immerse myself in the world of synthetic biology. I believe that creative musical processes might also inspire and inform the synthesis of new biological forms in much the same way that the processes to engineer bacteria to synthesize fluorochemicals inspired and informed the composition of *SinFonia*. My work shows how to make a piece of music as though one were processing DNA sequences. Despite the fact that the composition's final stages involved a great deal of Dionysian anarchy, I believe that it could be possible to formalize what I did at this stage too with rules. Thus, the question that emerges in the back of my mind is: Would there be a way of synthesizing meaningful DNA sequences as if one was composing music? I am itching to initiate the experiments!

Recordings of the composition were released on SoundClick.

The individual enzymes are as follows:

Aldolase: https://soundclick.com/r/s8h8qm
Fluorinase: https://soundclick.com/r/s8h8ql
Aldehyde Dehydrogenase: https://soundclick.com/r/s8h8qk
Isomerase: https://soundclick.com/r/s8h8qj
Kinase: https://soundclick.com/r/s8h8qi
Nucleosidase: https://soundclick.com/r/s8h8qh

The final *SinFonia* piece is available at the following link:
https://www.soundclick.com/music/songInfo.cfm?songID=14247892

# BIBLIOGRAPHY


01. Belgum, E., Roads, C., Chadabe, J. Tobenfeld, T. E. & Spiegel L. (1988). A Turing Test for 'Musical Intelligence? *Computer Music Journal*, *12*(4):7-9.
02. Cage, J. (1994) *Silence: Lectures and Writings*. London: Marion Boyars. ISBN 978-0714510439
03. Dabby, D. S. (1996). Musical variations from a chaotic mapping. *Chaos 6*:95–107.
04. Daly, I., Nicolaou, N., Williams, D., Hwang, F., Kirke, A., Miranda, E. & Nasuto, S. J. (2020). Neural and physiological data from participants listening to affective music. *Scientific Data 7*(1). https://doi.org/10.1038/s41597-020-0507-6.
05. Davidson, R. (1996). *Brain Asymmetry*. Cambridge (MA): The MIT Press. ISBN-13: 978-0262540797.
06. Dodge, C. (1988). Profile: A Musical Fractal, *Computer Music Journal 12*(3):10-14.
07. Hugdahl, K. and Westerhausen, R. (Eds.) (2010). *The Two Halves of the Brain*. Cambridge (MA): The MIT Press. ISBN-13: 978-0262014137.
08. Jacobs, J. P. and Regia, J. (2011). Evolving Musical Counterpoint: The Chronopoint Musical Evolution System, *Proceedings of the First International Workshop on Evolutionary Music – 2011 IEEE Congress on Evolutionary Computation*, New Orleans, USA.
09. McGilchrist, I. (2009). *The Master and His Emissary: The Divided Brain and the Making of the Western World*. New Haven (CT): Yale University Press. ISBN-13: 978-0300148787.
10. Miranda, E. R. (2020). Genetic Music Systems with Synthetic Biology, *Artificial Life 26*(3):366-390.
11. Miranda, E. R. & Castet, J. (2014). *Guide to Brain-Computer Music Interfacing*. Springer.
12. Nietzsche, F. ([1872]1993). *The Birth of Tragedy*. London: Penguin Classics (New Edition). ISBN-13: 978-0140433395.
13. Springer, S. P. & Deutsch, G. (1998). *Left Brain, Right Brain: Perspectives from Cognitive Neuroscience*. New York (NY): W H Freeman. SBN-13: 978-0716731115.

# REWRITING THE SYMPHONY OF LIFE WITH SYNTHETIC METABOLISM – CAN ENZYMES PLAY MUSIC?

by Nicolas Krink, Manuel Nieto-Domínguez & Pablo I. Nikel

The 21st century poses challenges to humankind that require a major leap forward in designing technologies that can be extended towards – and that can take advantage of – the realm of living cells. We are experiencing a fundamental transition of biology, similar to the one that chemistry underwent some 100 years ago when it morphed from a rather descriptive science into the productive science of synthetic chemistry we know today (Yeh & Lim, 2007). Among other ambitions, synthetic biology (and synthetic metabolism in particular (Cros et al., 2022; Erb et al., 2017) seeks to transform cells into living factories by both rewriting and upgrading their metabolism (Nielsen, 2017; Nielsen & Keasling, 2016; de Lorenzo et al., 2018) using cutting-edge genome and gene modification tools (Zhao et al., 2021). Through these modifications, which comprise the core of the field termed "metabolic engineering", the modified cells can produce chemical building blocks for a greener, more sustainable future (Chen et al., 2020). However, even bacteria (which are among the simplest living organisms) are incredibly complex and unpredictable.

We tame environmental bacteria in the Systems Environmental Microbiology group in order to develop sustainable alternatives to conventional industrial processes. To this end, we modify bacterial cells to render them capable of performing tasks that they could not execute previously (Volke et al., 2020; Weimer et al., 2020). We often deal with processes that do not occur naturally (complex metabolic pathways leading to novel compounds, for instance) (Cros et al., 2022). One of the main questions that we want to address in our work concerns the extent to which we can update the periodic table of life. All known living organisms are formed essentially from carbon, hydrogen, oxygen, nitrogen, phosphorous, and sulfur. Our goal is to incorporate new 'notes' (chemical elements) into the music of life (Nieto-Domínguez & Nikel, 2020; Pardo et al., 2022). Including new chemical atoms opens up a new world of products that we can produce with our microbial cell factories. However, finding efficient ways to biologically produce compounds, not only novel ones but also those that carry xeno-elements, is a daunting task. It usually starts by taking a good look at the highly diverse sea of life and fishing for key chemical elements (and the pathways that incorporate them into metabolism) from different species – such as genes or proteins. With these elements at hand, we want to build a synthetic metabolism that plays a desired 'melody' (the production of our compounds of interest) without 'dissonances' (no by-products). We need to learn and to understand the 'natural' metabolism's notes, instruments, and sounds in order to expand the cell's inherent metabolic 'music' to something new-to-nature – and even towards a new SinFonia, which is not a misspelling, but is rather the name of one of our group's major, EU-funded projects (Calero et al., 2020).

SinFonia aims to rewrite the metabolic music of a living cell, ideally leading to the production of fluorochemicals (chemicals that contain the element fluorine). These compounds appear in several forms in modern industry; for instance, they are the building blocks for different types of materials and constitute the key components of an increasing number of both pharmaceuticals and agrochemicals. In fact, many widespread products such as the polymer Teflon™ (polytetrafluoroethylene), the antidepressants Celexa™ (citalopram) and Prozac™ (fluoxetine), or the herbicide Treflan™ (trifluralin) contain fluorine in their molecular structures (Mei et al., 2019; Harsanyi & Sandford, 2015). Thus, the production of fluorochemicals is a particularly challenging – and exciting – goal of modern metabolic engineering. Fluorine is not even an element that is commonly found in living cells (O'Hagan, 2008). Thus, we need to fine-tune this new element, fluorine, into the natural melody of the cell in order to create our new-to-nature products, but this usually leads to dissonance. Our mission is to adjust the cell's molecular instruments, the enzymes, and the overall melody in order to incorporate a new 'chemomusical note', fluorine, within the symphony of life. At present, after years of effort, our research group has managed to assemble a pathway by encoding enzymes that can effectively take a mineral fluorine salt and can convert it into an organic fluorinated compound. This is the starting point for developing the bio-based production of valuable fluorochemicals. This was the project's status when Eduardo Reck Miranda, a composer, first joined our group.

The idea of mixing science and art was, of course, very appealing – although we were probably a bit skeptical about the outcome of a collaboration of this sort, looking at the project from a retrospective point of view. As scientists, we face challenges on a daily basis, and we often need to change our perspectives in order to solve them; however, we remain scientists no matter what (which, in practical terms, means that we resort to the same set of tools and strategies when addressing a problem, more or less). We hoped that someone from a completely unrelated field, and someone as creative as an artist, would reveal a different and hitherto unexplored perspective of our routine work. In addition, art impacts the public perception in ways that go beyond what the usual channels for science dissemination can reach. Therefore, we were somehow expecting that the collaboration might boost the awareness of our projects, goals, and results. However, the connection between science and art has also been shown to achieve something beyond our imagination.

Making these wishes a tangible reality appeared challenging in the beginning. As the artist-in-residence was a musician, we thought that music seemed to be a self-contained universe – with its own rules and language – but one that is not possessed of an immediate translation into the physical, concrete world in which science operates. Historically, art and science went hand in hand, and it was hard sometimes to tell the difference between them. Leonardo da Vinci's transformative work comes immediately to mind. Visual artists like him wanted to understand the mechanism that lay behind what they saw in their environments. Nevertheless, five centuries have passed since da Vinci's era and science and art have since evolved far beyond what renaissance society could even have imagined. In contrast to the connection between science and visual art, the translation of science into music was, to us, a goal that was more difficult to approach. Under these circumstances, how might we establish a fluid dialogue between these two realms? What kind of output could organically merge metabolic engineering and music? Those were some of the questions that we asked ourselves before the collaboration began.

Nevertheless, all of our concerns vanished when we met Eduardo Reck Miranda. He was not only a talented artist, but also an expert on productively bringing science and music together. He already had several ideas on how to approach the biological problem from an artistic perspective, and we had fascinating discussions about selecting and customizing the strategy most suitable to our enzymatic pathway's ability to bring fluorine to life. In our opinion, the residency's deep core involves translation. While genes are translated into proteins as part of the flow of information in virtually any living cell, the artist-in-residence skillfully translated our proteins into... music (Miranda, 2020). The goal of developing a more sustainable process for fluorochemicals was another layer of translation, and the global process can be seen as expressing science in terms of the language of music. In fact, converting the project's goal into music was one of the residency's most exciting challenges. This is probably because a goal is something that is relatively arbitrary so we could not rely on a more structured approach, much like the one applied to the translation of amino acid sequences. In our case, we decided to go from a 'metal-sounding' composition that slowly turns into something more 'melodic' in successive cycles. This evolution represents the transition from the current hazardous environmental processes, by which fluorochemicals are produced, to establishing more sustainable procedures. Of course, we were aware that 'metallic' or 'melodic' are very subjective concepts, but we understood that subjectivity was also a part of this crosstalk between biotechnology and music.

This idea was one of our contributions, as scientists to the residency, although in general terms our participation was focused on selecting among the proposals made that fit the best with our enzymatic pathway for fluorination with consultation from the artist-in-residence. We also provided all of the data required for the translation, including the amino acid sequences and the enzyme kinetics. Transforming an enzyme into music and sound implied an actual mental shift. We are used to looking at them in structures and models, but we never actually get to hear them.

Surprisingly, one of the collaboration's most interesting moments was an idea that did not end up becoming part of the project. During the discussions on converting an amino acid sequence into music, the artist suggested the possibility of walking the opposite path, turning a musical composition into an amino acid sequence, and expressing and studying this new protein. We ruled out the practical implementation of the idea, because producing a catalytically active protein or even a soluble from a piece of music is technically very challenging. However, the concept is fascinating. Proteins in nature are not a random chain of amino acids. On the contrary, they obey strict rules that we do not fully understand yet, but we do know that only certain sequences of amino acids can form viable proteins. Interestingly, the same overall concept applies to music: musical composition is not a succession of random sounds. There are rules, both explicit and implicit, and an underlying structure, which is particularly perceptible in classical music. Is it possible to create a dictionary that translates the rules of music into the rules of the protein world? An answer to this question would be a remarkable achievement from both a scientific and artistic perspective.

Another enlightening experience took place when we invited the artist to present his work during our weekly laboratory meetings, which are usually characterized by hardcore scientific discussions. This was the first time that the whole team was exposed to this sort of collaborative project. We were delighted to see the results that were achieved in the multiple interactions that Eduardo Reck Miranda had with other research groups and, of course, this presentation whetted our appetite to experience such a collaboration ourselves. The only regrettable fact of this fascinating endeavor was that it took place remotely, because of the COVID-19 pandemic. Therefore, we missed the experience of having the artist physically sharing the laboratory setup with us and connecting with those group members that were not directly involved in the residency's activities. However, we enjoyed what has been an enlightening experience for all of us, even with the remote 'residency'.

Our research also transforms natural organisms into cellular factories, changing and extending their format similarly to transforming DNA-encoded enzymes into music. Listening to the sound indicates harmony, but with elements of dissonance, much like if a bit of the chaos that is intrinsic of living organisms had invaded the musical universe. This is something particularly meaningful for us, because 'chaos' – when applied to life – is not the absence of order, but an order that we do not yet fully understand. Based on the laws of chemistry and physics, the building blocks of life (nucleic acids, proteins, carbohydrates, lipids, and cofactors) interact, thereby developing a network of such complexity that our current capacity to predict outcomes is limited at best. This unpredictability, which looks like an apparent chaos, was also somehow translated by the artist, and made its way into the final music piece. The result led us to reflect upon how we might tune the music of life without dissonance and disruption. However, it is not only a matter of lack of knowledge: one may also ask if chaos is not an intrinsic (and even necessary) part of life. After all, the laws of biology are not deterministic, but probabilistic; living organisms are also not static, since life is about change and evolution.

The residency was also interesting as a way to broaden our own knowledge horizons. We learned that communication between art and science is possible and smoother than expected. Another take-home message was the need for synergies in the achievement of our goal. Prior to the residency, we used to view art as a tool to communicate science's message. This experience has changed our perspective: now we appreciate the collaboration between music and science from a different perspective, and we recognize this interaction as a powerful approach to develop novel auditory art. As scientists, this led to a change of standpoint – zooming out in order to get a different angle from our work, and then zooming back in to solve a challenge. Conversely, the experience also highlighted the differences between the two worlds: the scientific work needs to be continuously validated by natural reality, whereas art – in this case, music – can fly more freely. In fact, this difference, which defined the work dynamics, was explained previously with the artist making the proposals and the scientists narrowing the possibilities in order to fit the experimental data.

The residency's final output was very interesting, even though the development process was probably the best part of the collaboration. Hosting an artist-in-residency in a laboratory environment would be welcomed by us anytime, as it opens up a laboratory's creativity and diversity of perspectives. Changing one's perspective might allow new endeavors and projects. At the research level, it is unlikely that the composer's methods will be applied to our daily work. What we mean is that converting proteins into music will not be useful for our research, but the concept that biological information can be meaningfully translated into other forms of information is an inspiring idea that we will not soon forget. Therefore, we would like to highlight the view that art is not useful only for science communication, but also in the exploration of possible crossovers and in extending the scope of both research and art. Having an open position for an artist-in-residency who explores music as an art form, compared to (future) product or industry design, indicates the closer relationship between art and biological research, particularly given that we are both trying to create a physical product. Overall, we would definitely recommend having an artist or designer in residency in laboratory environments. It enriches all viewpoints. The key is to have open-minded scientists that do not view the resident's presence as additional work, but rather as an outstanding opportunity. Artists and scientists look at the same coin, called nature, from different sides and work together to complete the picture. For us personally, it has been a unique and very gratifying experience.

By way of closing, it is worth remembering one of the most iconic quotes by the German philosopher Friedrich Nietzsche – who has been already cited by Eduardo Reck Miranda – "without music, life would be a mistake". As researchers, we would not go so far as to claim that this is the case, but after this residency we can claim that music is closer to life sciences than we were inclined to think at the beginning.

# BIBLIOGRAPHY


01. Calero, P. *et al.* (2020) A fluoride-responsive genetic circuit enables *in vivo* biofluorination in engineered *Pseudomonas putida*. *Nat. Commun.* 11, 5045
02. Chen, Y. *et al.* (2020) Systems and synthetic biology tools for advanced bioproduction hosts. *Curr. Opin. Biotechnol.* 64, 101-109
03. Cros, A. *et al.* (2022) Synthetic metabolism for biohalogenation. *Curr. Opin. Biotechnol.* 74, 180-193
04. de Lorenzo, V. *et al.* (2018) The power of synthetic biology for bioproduction, remediation and pollution control: The UN's Sustainable Development Goals will inevitably require the application of molecular biology and biotechnology on a global scale. *EMBO Rep.* 19, e45658
05. Erb, T.J. *et al.* (2017) Synthetic metabolism: metabolic engineering meets enzyme design. *Curr. Opin. Chem. Biol.* 37, 56-62
06. Harsanyi, A. & Sandford, G. (2015) Organofluorine chemistry: applications, sources, and sustainability. *Green Chem.* 17, 2081-2086
07. Mei, H. *et al.* (2019) Fluorine-containing drugs approved by the FDA in 2018. *Chemistry* 25, 11797-11819
08. Miranda, E.R. (2020) Genetic music system with synthetic biology. *Art. Life* 26, 366-390
09. Nielsen, J. & Keasling, J.D. (2016) Engineering cellular metabolism. *Cell* 164, 1185-1197
10. Nielsen, J. (2017) Systems biology of metabolism. *Annu. Rev. Biochem.* 86, 245-275
11. Nieto-Domínguez, M. & Nikel, P.I. (2020) Intersecting xenobiology and *neo*-metabolism to bring novel chemistries to life. *ChemBioChem* 21, 2551-2571
12. O'Hagan, D. (2008) Understanding organofluorine chemistry. An introduction to the C–F bond. *Chem. Soc. Rev.* 37, 308-319
13. Pardo, I. *et al.* (2022) A nonconventional Archaeal fluorinase identified by *in silico* mining for enhanced fluorine biocatalysis. *ACS Catal.* 12, 6570-6577
14. Volke, D.C. *et al.* (2020) *Pseudomonas putida*. *Trends Microbiol.* 28, 512-513
15. Weimer, A. *et al.* (2020) Industrial biotechnology of *Pseudomonas putida*: Advances and prospects. *Appl. Microbiol. Biotechnol.* 104, 7745–7766
16. Yeh, B.J. & Lim, W.A. (2007) Synthetic biology: lessons from the history of synthetic organic chemistry. *Nat. Chem. Biol.* 3, 521-525
17. Zhao, D. *et al.* (2021) CRISPR-based metabolic pathway engineering. *Metab. Eng.* 63, 148-159

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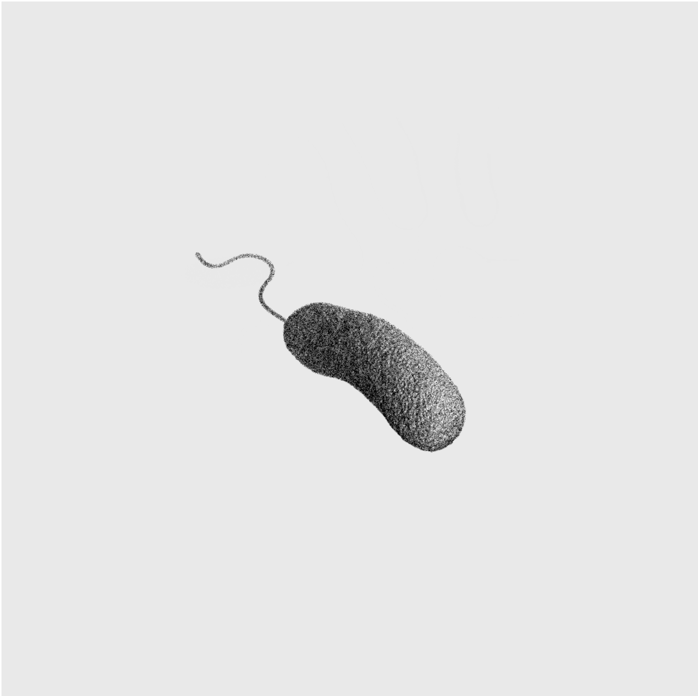
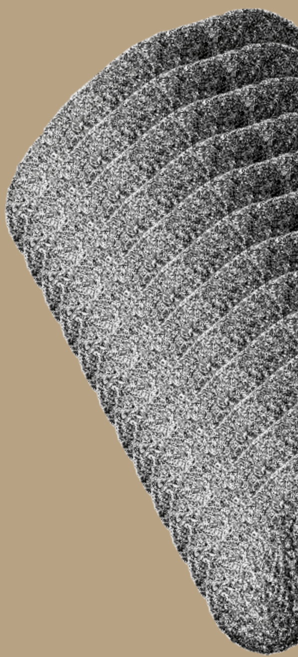
MADONNA




*Madonna has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement H2020-FETOPEN-1-2016-2017-766975.*

# MADONNA

Since the 19th century, industrial production has been operating mainly in one direction – from resources to products. These unsustainable processes generate tremendous amounts of waste that massively affect the environment, thereby transforming the planet's climate.
Madonna explores new-to–nature reactions to reverse this unsustainable system by integrating living matter into the process. These reactions can be carried out by living organisms, provided that new-to–nature reactions can be included into their genome. Madonna investigates the use of genetic engineering, directed evolution, chemo-robots, and complex computer models to help microorganisms incorporate these new abilities. This will allow them to turn industrial waste into a resource, reversing the process and closing the cycle of production.



# VICTOR DE LORENZO – THE MOLECULAR ENVIRONMENTAL MICROBIOLOGY LABORATORY

The Molecular Environmental Microbiology Laboratory at CSIC Madrid has a formidable mission: the production of biological agents for biosensing, remediation, and valorisation of chemical waste that is otherwise dumped into the Environment. To this end they use the Gram-negative soil bacterium and plant-colonizer *Pseudomonas putida.*

# LARA TABET

Lara Tabet is a Lebanese clinical pathologist and visual artist. Her work at the intersection of photography, biology, and the environment is rooted in research and experimentation. She is interested in the interaction between photographic and biological materiality, while questioning the porous boundaries between analog and digital languages.

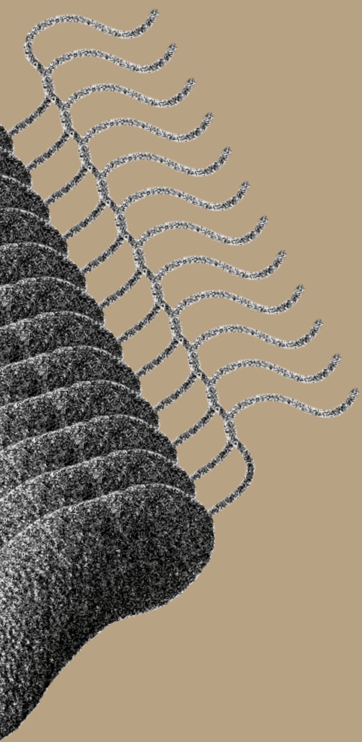


fig. 3.1 The self-replicating microorganisms *Escherichia coli* and *Pseudomonas putida* are bacteria strains that are used to implement new-to-nature reactions.

# MULTISCALAR FORMS OF RESISTANCE: THE MOLECULAR SWITCH, THE BACTERIUM, THE INDIVIDUAL, AND THE STATE

by Lara Tabet

For the longest time, my answer to the question: "What do you do?" was to say that I am either an artist or a medical doctor, but never both depending on the context and interlocutor. It was only fairly recently that I have come to terms with this double identity of sorts. Throughout my long years in medical studies, I developed an art practice alongside medicine that I kept totally separate. I used image-making as both a seductive and transgressive tool and this work, conducted in parallel, aimed to reaffirm the presence of the sexual body in the public space within the context of post-war Beirut. Three years ago, almost insidiously so, my two professions intersected as I began to explore biological materials through the medium of photography. I started photographing through the lens of a microscope as a result of spending long hours looking through one. Soon afterwards, I incorporated microscopic photography into my artistic practice as an essential visual tool. My methods then expanded to encompass a wider reflection upon the forensic image, investigating the boundaries between the diagnostic apparatus and the artefact.

As a result of this intersection, and the works that flowed therefrom, when posed with that same and somewhat dreaded "what-do-you-do?" question today, I reply that I am a visual artist and a medical doctor specialized in clinical pathology.

The term pathology itself is derived from the Greek words *pathos* and *logos*, as in "the study of suffering". As a medical specialization, it is concerned with the diagnosis of diseases through the analysis of tissue cell and body fluid samples, and encompasses several branches such as hematology, biochemistry, blood banking, as well the fields of microbiology and molecular biology; I had already incorporated these two last fields into my art practice, prior to my most recent work in the Molecular Environmental Microbiology Laboratory in Madrid, albeit separately.

The first instance was in *.DNA* (2019)[1], a project that interrogated DNA, both as content and container, and as a potential medium for encoding and storing archival images. It questioned the means by which we protect the physicality of a photo object, in an archive, in the age of dematerialized information.

My second foray into using pathology in my photographic work was in *The River* and *Eleven Fragmented Seas*[2] (2018-2020) in which I used photographic color film as a bacteriological incubator. I introduced microorganisms, collected from the water samples of multiple sites along the Beirut River and the Lebanese littoral, which were then allowed to alter the chemistry of the analog film emulsion process, thereby intersecting forensics bacteriology with landscape photography.

In the summer of 2020, I came across Biofaction's open call for an artist residency in a molecular microbiology laboratory. On the basis of the two aforementioned projects, the prospect of immersing myself in this sort of work was incredibly exciting for me, given that it would allow for me to bring both of my careers, and my interests in experimental photography and environmental/synthetic microbiology, to an even keener convergence.

The Laboratory of Environmental Synthetic Biology (headed by Prof. Víctor de Lorenzo) produces biological 'agents' for biosensing, and for the remediation of chemical waste through the use of the Gram-negative soil bacterium *Pseudomonas putida*. This was a perfect fit for my concerns with ecotoxicology and my previous research into the microbiology of water bodies. My initial proposal for the project read:

> "I am particularly interested in your research, in how it hinges upon the notion of reversal: that of the central dogma, that goes from genetic material to protein, and that of the industrial production cycle through cyborgization of the bacterium *P. putida*. With these shifts in paradigms as my point of departure, I would like to create an audiovisual piece that makes use of formal, social and performative strategies to investigate the braiding of ecological science

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[1] Documented at: https://www.ltabet.com/DNA

[2] The River (2018) documented at: https://www.ltabet.com/The-River and Eleven Fragmented Seas (2018-2020) documented at: https://www.ltabet.com/Eleven-Fragmented-Seas

with fiction, where prevailing narratives can be entangled, twisted, imagined, reimagined, and manipulated. I aim to contemplate microscopic life through the lens of body politics and scientific semantics, where the bacterium's modified body interrogates how under such scale and conditions the ideas of agency, transgression, performance may be approached."

I received news of my selection in November 2020. I was in Brazil at the time, and EU borders were still closed to me because of restrictions imposed by the COVID-19 pandemic. There was no way for anyone to foresee when I would be able visit the lab. Over the course of one year, I met with the team regularly online by attending their weekly conferences and I became familiar with their ongoing research. In May 2021, as soon as travel regulations allowed for it, we scheduled my first in-person visit. Prior to my arrival, I asked to have recorded private zoom conversations with each member of the team, as a way to break the ice, to learn about what they were currently working on, and to begin to imagine what form my own project would eventually take.

Once in the lab, I shadowed the scientists for the first few days, actively brainstorming with them. It became clearer to me, over time, how devising biotechnological tools preceded their potential widespread applications by many steps, and this allowed for me to better frame my project. As a clinical microbiologist, I was quite familiar with the world of laboratories, with benchwork and the handling of microorganisms. I was accustomed to looking for and identifying pathogenic bacteria, primarily ones that lead to diseases in people, assessing these bacteria's sensitivities to antibiotics, and studying their molecular mechanisms of drug resistance. However, I found that synthetic microbiology was very different in many respects; in this area, a non-pathogenic organism is engineered through the addition and deletion of genes to 'perform' new tasks in specific environments. This becomes what is called a biological chassis, a cell factory the production of which depends upon the exogenous genetic inputs given thereto. It was this microscopic performance-on-command that interested me, given that performance and performativity were concepts that I often explored in my art practice.

I treat photography as a spectrum that oscillates between the act of the documentation of space and as a performance for the camera. At times, image-making becomes a transgressive gesture for me to re-appropriate the public urban sphere and/or to reverse the male gaze in the representation of the queer Arab body in liminal spaces that exist at the edges of privatization.[3] At other times, photography has been a way for me to deconstruct the aura of the figure of the 'healer' across both western and traditional medicine perspectives.[4] However, when working with tiny living organisms, such as bacteria, performativity became multi-scalar, functioning on two corresponding scales with each having their own spatio-temporal frames of reference.

The first scale existed at the macro level and corresponded with my actions as an artist. For example, in *The River* and *Eleven Fragmented Seas* (2018-2020), it was the actions of sampling water, culturing bacteria, identifying it, and re-inoculating it onto photographic film. The symbolism of this gesture was one of ritual, but also one of transgression. As Lebanon's coastline has been heavily privatized and has become replete with cement, due to the illegal construction that encroaches on public land, sampling water every 20km first meant finding access to the sea to begin with, and sometimes trespassing on (ostensibly private) property in an act of re-appropriating public space.

The second scale functioned at the microscopic level, at the scale and the resolution of the bacterium; it was the sum of the microbial processes that altered the film's chemistry in this case.

The resulting image was not a direct visualization of the microorganisms, but rather was an indirect indicator of their presence. This involved posing the question of how one can interpret this non-human information. What are our frames of reference? How can scalar differences help us to think outside of our common perceptions, and how might they allow us to think of new modes of languages and possible meanings and collaborations?

## Microperformativity

Scholar and art curator Jens Hauser, in a volume edited together with artist Lucie Strecker, posited what they believe led to the emergence of the

[3] Examples of this can be seen are in the following works: *The Reeds* (2012), available from: https://www.ltabet.com/The-Reeds and https://www.ibraaz.org/essays/165. And: *Underbelly* (2018), available from https://www.ltabet.com/Underbelly.

[4] Here, Lara Tabet references her work *The Return of the Old Man*, not available online at the time of publication.

neologism "microperformativity", notably through the re-definition of the notion of the body to include non-humans and in terms of the shift in performativity from physical gestures to physiological processes:

> "Artists, beyond employing genes or cells just to act as ontologized proxies for (human) identities, also stage proteins, enzymes, bacteria or viruses, among others, indicating a growing interest in non-human agencies at large." (Hauser, 2020:12)

Microperformativity, thus, crosslinks performance and media theory with science and technology, redirecting the gaze towards these 'other-than-human agencies' in the process and challenging the human scale as central.

Early on during my process, I knew that I had wanted to build upon my experiences in my previous works, which had featured intersections of performance, photography, and bacteriology. As an art form, performance's ephemeral nature addresses the necessity of its documentation. This new shift away from the human scale and resolution created both new limitations and possibilities. As noted in a conversation between artist Lucie Strecker, Jens Hauser, and historian and philosopher of science Hans-Jörg Rheinberger (Hauser & Strecker, 2020), this shift in scale implies manipulating both spatiality and temporality, as well as enlarging what is invisible, and the compression and dilation of time become a necessary visualization tool in this pursuit.

> "'What is too big must be downsized' and 'What is too quick to be observed must be slowed down; and what is too slow to be observed must be accelerated' [sic]." (Hauser & Strecker, 2020:66)

One thing became evidently clear to me from my many conversations with the scientists in Víctor de Lorenzo's laboratory, which was that any 'performance' that we were going to stage would take place over a certain period of time, the scale of which was bacteriological. That is, the performance should take both the specific demographics of the bacterial cycle of growth and the spatiality of the laboratory setting, in which contamination can be avoided, into account. This meant that the final work would definitely have to be the documentation of the performance, rather than the performance itself. As a visual artist trained in photography, I was drawn to this idea; after all, photography and video have been the major tools documenting performance art from its inception because of the way in which cameras capture time. There is an inherent contradiction in the act of recording and reproducing live art, of course. For me, what was particularly interesting in this practice was the reliquary connotation of what sorts of images and imaginaries could withstand.

Another limitation that I kept in mind was that the necessary visualizations of microbial processes were created artificially. In order to make the bacteria visible, they were grown into a bacterial culture, made of colonies rather than an individual bacterium; in this case, the clone becomes the substitute for the cell. Other methods of visualization and verification included the introduction of a gene expressing a fluorescent protein that conferred a color (such as the infamous GFP green fluorescent protein), or a LUX gene that conferred bioluminescence, or even an antibiotic resistance gene that allowed for the selection of our modified organisms in a culture media that included that same antibiotic and that would be lethal to other bacteria.

All of these methods required specific timeframes. We allowed 24 hours for bacterial growth on solid media, and around three hours in liquid media, in order to achieve growth and to reach the optimal optical density in which these performances could then take place.

With all of these limitations in mind, I set out to look for a specific microperformance that I wanted to stage. I ended up developing two separate microperformative bodies of work. I learned about the 'suicide gene', during one of my talks with Dr. Belen Calles at the lab, which is a lethal gene that codes for a restrictive enzyme that would destroy the bacterium's DNA and would cause its death once induced. It is similar to an ON/OFF switch, kind of like a bomb devised by the scientist to mass extinguish their culture at any point of their choosing. The technical term for this is "biocontainment", a strategy that is applied to ensure that harmful organisms remain confined to controlled laboratory conditions and are not allowed to escape into the environment. This gene became the basis of my first work/protocol.

**Necropoiesis**
Collaborators: Belen Calles, PhD & David Rodriguez Espeso, PhD

In *Necropoiesis*[5], I induced the bacteria *Pseudomonas putida* to self-destruct through a voice command. Once the death sentence was pronounced, the lethal gene was chemically induced and caused programmed cell death. I chose bioluminescent cloned bacteria in order to visualize bacterial death as a gradual loss of light emission.

We started by genetically modifying colonies of *Pseudomonas putida* KT2440 to constitutively express a LUX reporter gene, which caused the bacteria to continuously exhibit bioluminescence. The samples were then kept inside of a black box, one reminiscent of a camera obscura (one of the oldest types of photographic apparatus). Temperature was maintained at 30 degrees Celsius for optimal bacterial growth. I issued a specific command (a sentence) that chemically induced the lethal gene EcoRI, causing bacterial cell death by means of a voice-recognition software that we programmed. After the suicide gene's induction, a camera inside of the box recorded the loss of luminescence over a period of three hours. The sequential pictures showing the gradual waning of bluish light will be made into a video piece.

In parallel with this, we captured the loss in bioluminescence of another colony of *Pseudomonas putida* (also KT2440 and also induced to die on command) onto analog X-ray film every ten minutes. The sensitivity to the X-ray was proportional to the quantity of light emitted by the colonies and in which the images recorded show the waning of its light signals.

Both the rayographs and the video were recorded evidence of the human-induced microbial performance. The former is an analog snapshot, the latter a digital long exposure: An analog trace and its digital twin. Each one exists in its own frame of semiotics. The X-rays are reminiscent of the cosmic death of a star. They speak of (light) decay, of cosmic decomposition. The time-lapse video, conversely, exists in a moving image frame of reference, and the combination of motion blur and phosphorescence brings us back to the imaginary of the primordial soup.

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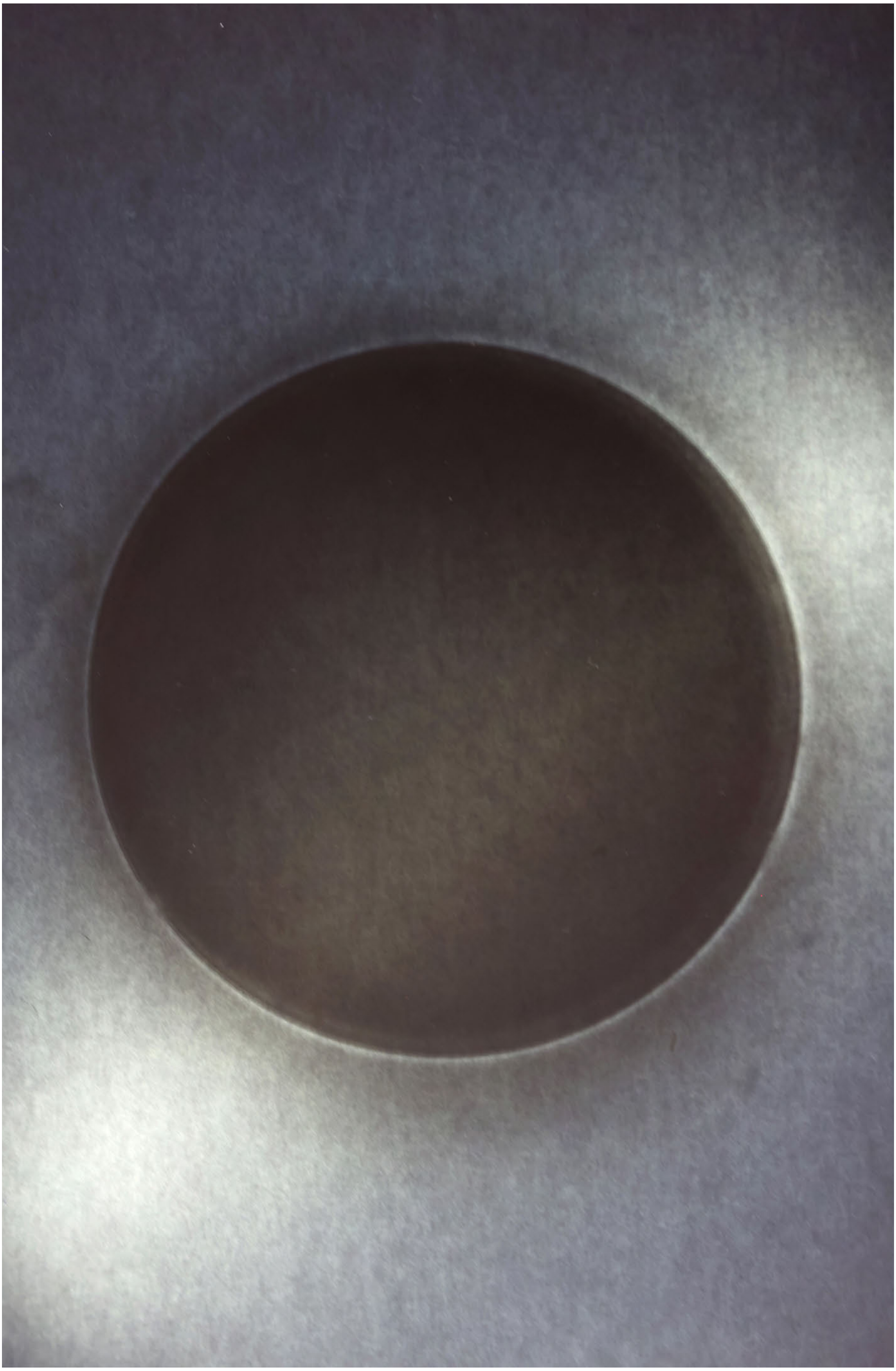
[5] *Necro* refers to Ancient Greek νεκρο-, *nekró-*, meaning "dead body". *Poiesis* is etymologically derived from the Ancient Greek word ποιέω, *poiéō*, meaning "to make". It is the root word of "poetry" and is used as a suffix in the biological term "hematopoiesis", the formation of blood cells.

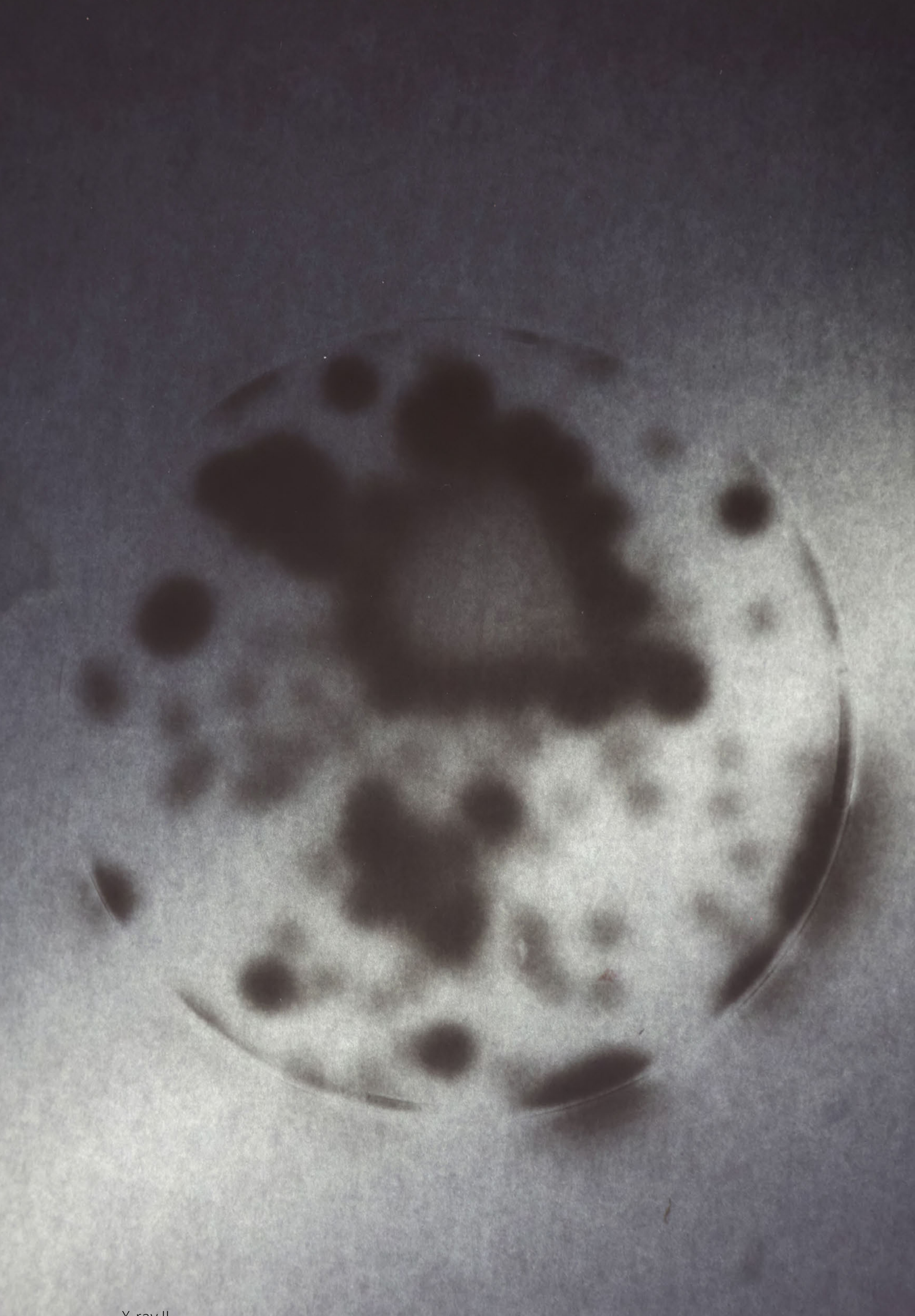
fig. 3.2 Digital animation I
Bioluminescent *Pseudomonas putida* induced to die.

fig. 3.3 Digital animation II
Bioluminescent *Pseudomonas putida* induced to die.

X-ray I

fig. 3.4 Recording of waning bioluminescence after death induction.





X-ray II

**fig. 3.5** Recording of waning bioluminescence after death induction.

In Plato's *Symposium*, Diotima described how mortals strove for immortality in relation to *poiesis*, and how an impulse beyond the temporal cycle of birth and decay lay in the act of creation itself. This triad of time/death/light questions the semantics of death and the correspondence between the macrocosmic and the microcosmic, perhaps through what Adolf Portmann described as penetrating beyond the limits of the mediocosm that governs our everyday views,

> "...into a submicroscopic world of molecular and submolecular forces, into a microcosm-we penetrate beyond the everyday zones into extraterrestrial spheres, into a macrocosm which determine our life on earth, our spiritual creation, our economic efforts." (Portmann, 1961:48)

Our experiment relied heavily on the kinetics of microbial growth and death. Each day, I would cultivate a new batch of bacteria, patiently waiting until it reached its optimal growth phase (as measured by optical density) so that it would display its maximal bioluminescence. Only at that point would I pronounce my lethal command.

It is a human characteristic of ours to assign our emotions and behaviors to other living creatures. Microbiology literature is crowded with vocabulary about choice/war/love. Bacteria are said to "make a choice to use a particular substrate" or to "need something", bacterial conjugation is equated with sexual mating, and there are countless references to bacterial "warfare" (Davies, 2010:721). Over the course of two weeks, I aligned myself to that calculated, cyclical rhythm of life and death that culminated in the visual documentation of what I came to think of, in anthropomorphic terms, as agony.

There was something ritualistic and hypnotic about performing such an act, looking for its evidence day after day. When I thought about these unicellular organisms at the origins of life, day in and day out, the words of evolutionary biologist Lynn Margulis came to mind, in that:

> "Life on earth is such a good story you cannot afford to miss the beginning...Beneath our superficial differences we are all of us walking communities of bacteria. The world shimmers, a pointillist landscape made of tiny living beings" (Margulis & Sagan, 1986).

I recently read Donna Haraway's book *When Species Meet* (2008). In it she mentions Margulis, pointedly stating that: "Reading Margulis over the years, I get the idea that she believes everything interesting on earth happened among the bacteria, and all the rest is just elaboration" (Ibid:31). Indeed, in her Serial Endosymbiotic Theory (SET), Margulis theorized that eukaryotic cells (cells with a nucleus including the cells in our human body) evolved from prokaryotic cells (aka bacteria). Vital organelles such as mitochondria, chloroplasts, flagella, and cilia could have entered the cell as an ingested prey or as a parasite and could have developed a mutually beneficial symbiotic relation with their host cell over time. This view positions 'symbiosis' as a major driving force behind evolution, thereby challenging competition and natural selection as its primary compelling process. This theory, one that was much disputed and ridiculed in the 1970s, is now widely accepted, as a recent new study led by evolutionary biologist William F. Martin traces back many of the genes integral to the functioning of cells of higher organisms to bacterial DNA.

Autopoiesis, or 'self-production', was a concept introduced in the 1970s by Chilean biologists Humberto Maturana and Francisco Varela. An autopoietic system was defined as one that was capable of producing and maintaining itself by creating its own parts through a network of inter-related component-producing processes (Maturana & Varela, 1973). The smallest recognizable autopoietic entity is a tiny bacterial cell and the largest is 'the symbiotic planet'. It was Lynn Margulis, and her long-time collaborator James E. Lovelock, who applied the concept of autopoiesis to the entirety of planet earth through the Gaia hypothesis which stated that every organism, and their inorganic surroundings on Earth, are closely integrated and form a single and self-regulating complex system, maintaining the conditions for life on the planet (Lovelock & Margulis, 1974).

This idea of self-regulated systems and symbiosis between humans and non-humans led me to the second protocol/artwork that I conducted during my residency, *Resilience Overflow*, which questioned the role of human and non-human alliances in the absence of the state.

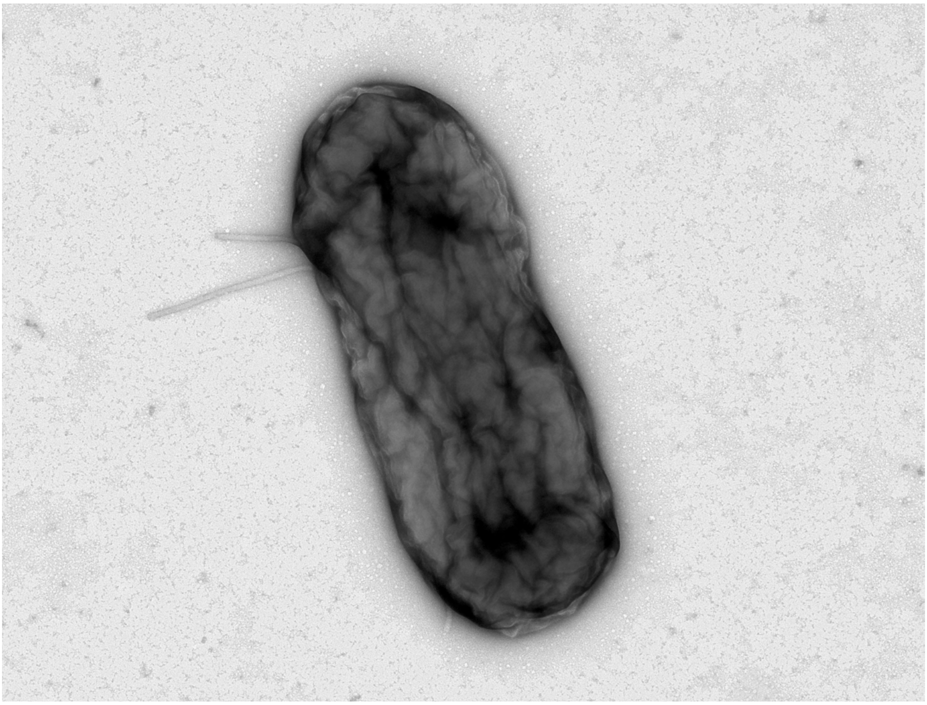
**Resilience Overflow**
Collaborator: Esteban Martínez, PhD

In *Resilience Overflow,* I considered the ethical and symbolic implications of hypothetically releasing modified organisms into the environment to remediate the shortcomings of an absent and neglectful government in a general sense, with regards to public health in particular.

This project consisted of genetically engineering my own fecal bacteria to produce the psychoactive human molecule Neuropeptide Y and speculating around the idea of releasing it into Beirut's water system. Neuropeptide Y is one of the key mediators involved in stress resilience in humans and has been shown to significantly decrease the effect of post-traumatic stress disorder. Beirut has recently suffered one of the biggest non-nuclear explosions that the world has ever witnessed. The capital city has also suffered the burden of a total financial collapse that has resulted in both a high rate of anxiety among its inhabitants and a massive medicine shortage, particularly in psychotropic medications.

Bacteria have the ability to exchange genes very easily and rapidly, even between different species, through tiny mobile circular DNA called plasmids. In this project, a plasmid construction containing the Neuropeptide Y gene was introduced into the bacterium through conjugation or 'mating'. The bacteria then incorporated the gene and began to produce its corresponding molecule, thereby becoming like tiny factories that can produce medications and distribute them on the scale of an entire city.

fig. 3.6 Electron micrograph of *Citrobacter amalonaticus* extracted from my gut and modified to express the gene for human Neuropeptide Y.



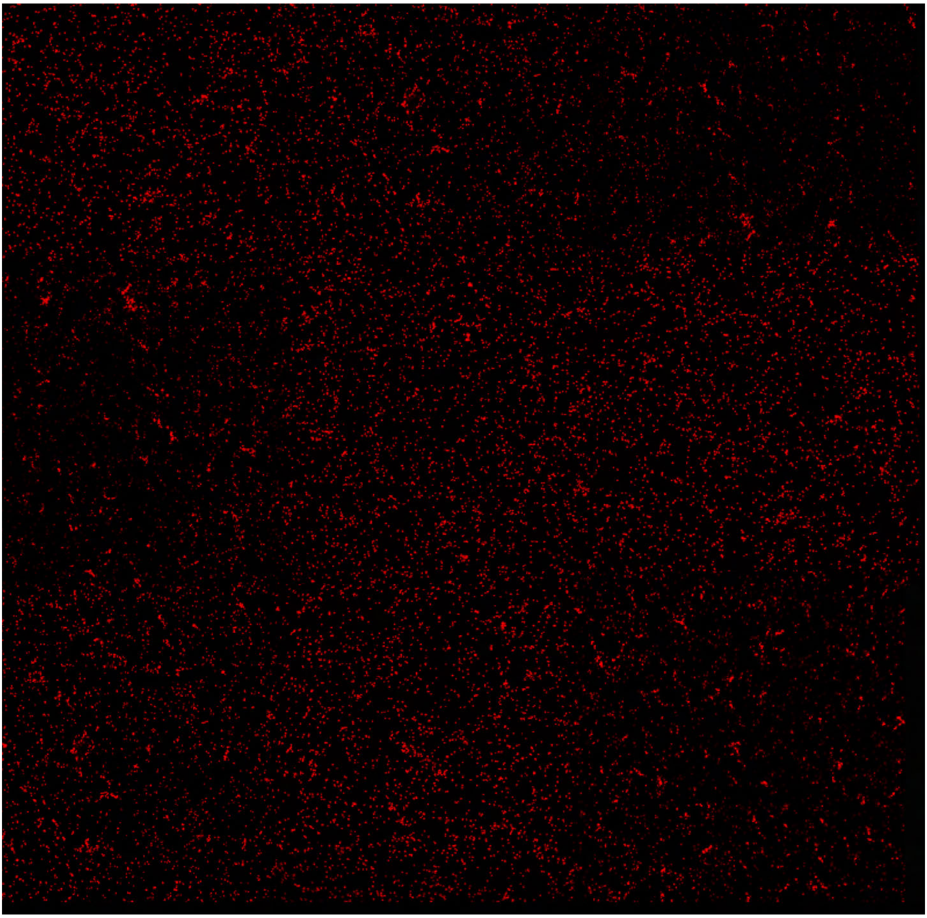
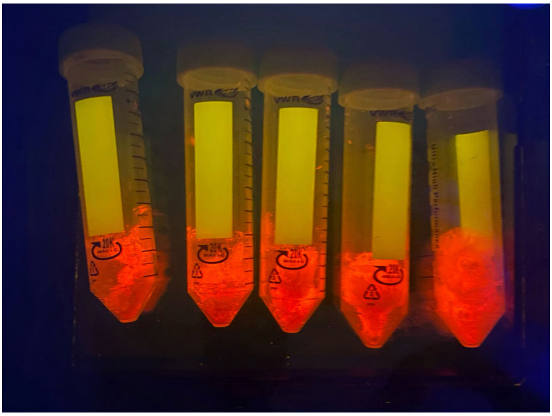


fig. 3.7 Confocal microscopy showing *Citrobacter amalonaticus* expressing Neuropeptide Y gene tagged with the fluorescent protein m-cherry protein.

As a long-time sufferer from irritable bowel syndrome (a chronic digestive disorder that is due to an imbalance in gut bacterial communities, or dysbiosis), I chose to use my own fecal bacteria to produce Neuropeptide Y as a way to draw attention both to the gut-brain axis and to the crucial role played by intestinal microbiota in influencing our emotional and cognitive behavior. The engineered bacteria were then freeze-dried into probiotic pills. From then on, the project becomes purely speculative.

What if I could re-ingest these, now psychoactive, probiotic bacteria and undertook a scatological gesture to release them into the 'wild', and completely untreated, Beirut wastewater system, the same one that flows freely into the sea? Would the psychoactive bacteria heal an entire population? In the absence of regulation and control provided by the state, what becomes of an individual's own power, role, and scope? What are possible modes of alliances that exist between humans and non-humans? How can we discuss agency and labor in wet media art? This project also considers and interrogates the multifold role played by water as a carrier of intergenerational trauma, toxicity, and healing.

fig. 3.8 Lyophilised bacteria containing human Neuropeptide Y gene.



**Center periphery: bio-poetics/bio-politics**

Being able to work in a state-of-the-art biotechnology laboratory, assisted by passionate scientists at the forefront of their field, was a monumental experience for me, one that I have sought for a long time. With this kind of access to science being impossible in our part of the world, it is important for me to ponder on what it means to be working in wet media art from the 'periphery' of progress. What does a specific geopolitical context bring into the conversation when using bio-art as a medium?

My work lies at the breaking point of tension between biopolitics and biopoetics and questions the ways in which we can navigate our bodies' livelihoods within toxic and corrupt state systems of control, all while thinking through living systems in order to stir new imaginaries and to consider possible futures.

fig. 3.9 *Resilience Overflow*, Film still I.

fig. 3.10 *Resilience Overflow,* Film still II.

**Cohabiting with toxicity requires constant negotiation**

During my last trip to Lebanon, almost two years after the port explosion, I was finally ready to visit my old neighborhood again. I went up to my old apartment, which was in a rundown building that had a panoramic view on the city's harbor. When the blast went off a few hundred meters away on that day, the impact caused the space to implode onto me. Managing to survive, I moved out of the ruined apartment in a matter of days.

Returning there, I rang the bell. My name was still on the door. A young woman on the other side opened it. I explained to her that I was the previous tenant, and that I needed to flush something down the drain. She said she understood and said that it was in no way a strange request.

# BIBLIOGRAPHY


01. Davies, J. (2010). Anthropomorphism in science. *EMBO Reports*, *11*(10): 721.
02. de Duve, T. (1978). Time Exposure and Snapshot: The Photograph as Paradox. *October*, *5*, 113-125.
03. Haraway, D. (2008). *When Species Meet*. Minneapolis: University of Minnesota Press.
04. Hauser, J. (2020). Microperformativity and Biomediality. *Performance Research*, *25*(3), 12-24, DOI: 10.1080/13528165.2020.1807745.
05. Hauser, J. & Strecker, L. (2020). Agency is Everywhere: An encounter with Hans-Jörg Rheinberger. *Performance Research*, *25*(3), 65-71.
06. Ku, C., Nelson-Sathi, S., Roettger, M., Sousa, F.L., Lockhart, P.J., Bryant, D., Hazkani-Covo, E., McInerney, J.O., Landan, G., Martin, W.F. (2015). Endosymbiotic origin and differential loss of eukaryotic genes. *Nature*, *524*(7566):427-432.
07. Lovelock, J.E. & Margulis, L. (1974). Atmospheric homeostasis by and for the biosphere: the gaia hypothesis. *Tellus*, *26*:1-2, 2-10, DOI: 10.3402/tellusa.v26i1-2.9731.
08. Margulis, L. & Sagan, D. (1986). *Microcosmos: Four Billion Years of Evolution from Our Microbial Ancestors*. Berkeley and Los Angeles: Univ of California Press.
09. Maturana, H. R. & Varela, F. J. (1973). *Autopoiesis and cognition: the realization of the living, its characterization and a model*. Amsterdam: North Holland Publishing Company.
10. Portmann, A. (1964). *Neue Wege der Biologie*. Munich: Piper, 1961 (engl. transl., *New Paths in Biology*, Harper and Row, New York, 1964, p. 48).

# TOWARDS A NEW COVENANT WITH NATURE – STARRED BY ENVIRONMENTAL MICROORGANISMS

by Víctor de Lorenzo

**A rendition of Lara Tabet's residence and how it inspired our research agenda**
**A bit of a background**

Lara Tabet's host laboratory is located within the so-called National Center of Biotechnology, at the National Research Council (CNB) in Madrid, specifically in the Laboratory of Environmental Synthetic Biology[1], which is led by this chapter's author. The team has been working on developing tools to address major environmental problems through the genetic engineering of microorganisms, and other methods which stem from contemporary molecular biology, for a long time (de Lorenzo, 2008; Dvořák et al., 2017; Schmidt & de Lorenzo, 2012). This laboratory has undergone profound technological changes in the last few years; for a long time, we were only able to program bacteria for environmental release (e.g., for bioremediation of chemical pollution) to a minor extent and with considerable unpredictability (Cases & Lorenzo, 2005). At present, though, we find ourselves in a position to undertake the application of modern genetic engineering and rational biodesign in earnest and with much better (and quite amazing) molecular tools because of the advances made within synthetic biology (Malik et al., 2021; Rylott & Bruce, 2020). Furthermore, the same molecular methodologies – made available only recently – offer open perspectives on the use of live constructs as agents that are able to deliver solutions to the phenomenally significant problems that we face as a planet, such as climate change (de Lorenzo, 2017; de Lorenzo et al., 2016).

[1] For more information, see: https://vdl-lab.com/

It is in this context that we launched Project Madonna, with the ambition of pushing the boundaries of familiar biochemical reactions towards new transformations, thereby bringing otherwise abiotic processes, which are typical of the chemical industry, into the biological fold. The long-term vision involves connecting the naturally occurring biogeochemical cycles with the human-created industrial metabolism for the sake of a sustainable element for recycling at a global scale. Our main approach to this end involved leveraging the immense problem-solving capacity of biological evolution to resolve challenges that are both multi-objective and that require optimization (Abraham & Jain, 2005). This is not just a theoretical occurrence, but it is also a powerful tool for biotechnologists when all-rational design, from first principles, is not possible because of excessive complexity. This is exactly the case for the Madonna project, given that it attempts to break the extant walls between living and non-living matter by pushing the limits of natural metabolism forward and towards a different type of chemistry. This endeavor requires the development of new-to-nature biological agents and will even require that we revisit contemporary biology's core foundations. One specific question concerns whether or not we can modify the so-called central dogma of molecular biology i.e., DNA goes into RNA and then goes into proteins, which can then propagate into metabolism (de Lorenzo, 2014). Instead, the abiding challenge concerns whether or not we can start with a reaction that, in principle, is not biological, eventually having it become encrypted in a biological system (Ralser et al., 2021). That is basically the project's mission and we have worked hard in order to make some progress in that direction.

Where are we now? The conventional approach to having bacteria running new reactions typically includes looking for gene-encoding enzymes that catalyze similar reactions and then applying adaptive laboratory evolution, i.e., ALE (Sandberg et al., 2019) to first diversify *in vivo* and then to select gene/enzyme variants that push the reaction towards the desired outcome stepwise. In fact, ALE reproduces Darwinian evolution in a test tube; the key difference being that the selective pressure and the fitness function are imposed by the human user in this case. We should note that the stratagem here involves the 'innovation' of something that exists: there is already a gene/enzyme in place and ALE enables its cognate DNA to explore a related sequence space in the pursuit of a new solution to the selection pressure. What can we do when the reaction, which is interesting to our concerns, is altogether unrelated to any other known biochemistry? In other words: how do we create authentic 'novelty' – not just innovation (Payne & Wagner, 2019;

Wagner, 2017)? Madonna's proposition involves cyclically exposing the abiotic reaction to the biological agent (which is programmed to evolve quickly) in such a way that it enables the development of a mutual interplay. This scenario might result in the modification of the biological component's genome to the point that the reaction is recorded in the DNA eventually and is later executed by the biological, live actor. This approach is expected to operate in a manner similar to the mechanism, through which many prebiotic reactions eventually become incorporated in, and run by, diverse living systems (Ralser et al., 2021). It goes without saying that the key question at stake here is that of 'creativity', an issue that directly connects the project with our artist-in-residence's interests.

## Experimental synthetic biologists meet a professional artist

It is not an uncommon occurrence to amateurishly discuss the connections between science and art in conversations over coffee with researchers. As a matter of fact, many scientists have a soft spot for specific artistic expressions (typically music) or other manifestations of plastic virtuosity. One can entertain at least two points of convergence between the two domains, one of which is definitely 'creativity'. That said, let me speculate at this point that creativity is mostly technological in the research world, not scientific proper. Science is about understanding. Technology and engineering are about doing new things, i.e., bringing otherwise non-occurring items into existence. Technology both enables and empowers science, but it is not science (Wolpert, 1994). An engineer's mindset for building a bridge or that of a biologist using CRISPR as a gene editing tool (Ahmad et al., 2018) are, in my opinion, comparable to that of a composer of a new symphony or a flamenco choreographer. Alas, the Renaissance tradition of artists-engineers (epitomized by Leonardo) diverged over the centuries into two separated and mutually alienated cultures. There is, however, a second layer of common ground between art and research: 'curiosity', i.e., the drive to wonder about how and why things function as they do, unveiling their inner logic and proposing scenarios that are new-to-nature. No wonder, then, that literature and other creative expressions have inspired scientific endeavors and that scientific views of the world have influenced the arts throughout history. The predicted consequence of all of these considerations is that if one puts creative and curious individuals together, whether it be an artist or someone from a research background, then something interesting is bound to happen. In any case: having an artist visit an experimental laboratory was as unusual and exotic as it could get, from our perspectives.

To be frank, we had never entertained the possibility of interacting with a professional artist within our own research team directly! The Madonna work program included having an artist-in-residence, but we had no clue about what that would involve in practice. It was our partner, Biofaction, who made the connections and who arranged the contact as a sort of 'blind date'. We started by inviting Lara to our seminars. She then took the time to talk to the members of the laboratory, one at a time, who explained to her what we were doing, what instruments we had, the molecular tools we used, the bacteria that we cultured, our biotechnological interests, etc. Most importantly, we explained both the interpretive frames that we systematically adopt to address reality (or at least the small portion of it that we handle) and the uncompromising way in which we deal with results when generating new knowledge in our field. She immediately became excited by what the possibilities of applying synthetic biology tools to environmental microorganisms (Martínez-García & de Lorenzo, 2017) might deliver in two specific aspects; the first being whether we can communicate with such microorganisms and tell them what to do and the second being a mirror endeavor, which was if we can empower microorganisms to tell us what to do. These generic ideas were boiled down into two distinct, but somehow connected, artistic projects that were the subject of countless discussions around assessing their technical feasibility, their safety, and the message to be shared with the general public. We were thrilled to witness how bringing an artist like Lara to our laboratory inspired her creative agenda in directions that she had never probably explored previously. We should note, though, that inspiration was bidirectional: we also discovered perspectives that we had never contemplated regarding our intimate interplay with the microbial world by talking to her.

## We are us and our microbiome

The first idea that comes to mind when discussing 'bacteria' is that of infectious diseases and, therefore, of enemies-to-defeat. This long-prevailing notion has been somewhat softened over the years with discoveries about the key role played by microorganisms in cycling elements and degrading toxic chemicals in the environment, thereby enabling the production of much-appreciated foods (cheese, beer, etc.) and these microorganisms even act as catalysts in some industrial processes (Ko et al., 2020). The big change in the way in which we deal with bacteria, though, was brought about by the more recent realization of our intimate interplay with our own microbiome (Blaser, 2014). We may not see it with the naked eye, but the large microbial community that inhabit our gut – and basically any other exposed surface of our body – has an influence not only on our health, but also on our very perception of reality, our mood, and the way in which we interact with each other. When we talk, kiss, touch, hug, share objects, etc., we interchange bacteria and end up having a shared microbiome that may come to pass into our intestine and might even form part of the so-called gut-brain axis and its constant traffic of neuroactive signals (Foster & Neufeld, 2013; Foster et al., 2017). How far such an influence goes is still a matter of much contemporary research. Sharing a microbiome is even entertained to enable the fostering of group cohesion, even influencing an entire population's mood. It is fascinating to realize how modern science, genomics in particular, has challenged traditional notions of philosophical and religious anthropologies of what it is to be human. Not only do we probably share nearly 99% of our DNA with chimpanzees (Swiss Institute for Bioinformatics, 2020) (and a good 40% with bananas! (Hoyt, 2021)), but we also sustain a constant circulation of bacteria among our body, with animals (Edmonds-Wilson et al., 2015; Stewart et al., 2018), with plants, and with the rest of the surroundings which form the material reality in which we find ourselves (Talbott et al., 2020). The environmental microbiome at large works as a sort of Ariadne's thread that connects every type of life form to every other type. We are part of a continuum that encompasses the entirety of the living world in which microorganisms fill the gaps between different actors. No wonder, then, that this raises questions about the notion of the 'self'. Our comprehension of ourselves cannot simply ignore the idea that we have a whole other self inside of us: the microbiome that inhabits our body. Spanish philosopher Ortega y Gasset stated his famous aphorism in 1914 that "… I am I and my circumstance …" but we might rightly amend it in 2022 to '… I am I and my microbiome …' No way these notions, which were amply discussed during Lara's stay, should go unnoticed among creative and artistic minds who are not devoid of political concerns, such as our visitors!

Given the growing awareness about the aforementioned gut-brain axis, a legitimate question is whether or not the deliberate spreading of mood-influencing bacteria through a large human population could ultimately have serious social consequences, even political ones, given that our perception of reality could be modified at a large scale. We are at this point far from that scenario technically, which is itself packed with considerable safety concerns, ethical issues, and clear risks of misuse. That said, we have the artistic freedom and ability to entertain and express not-yet-born futures with all their pluses and minuses in plastic forms as well as in provoking thoughts, reactions, and debates about such possibilities. Lara grabbed the opportunity to translate the issue into a thrilling artistic performance. The practical payoff of these discussions for our own scientific agenda was a realization of the current scarcity of technologies for microbiome engineering, in addition to big gaps in our understanding of how microbial communities both work and react to the introduction of a newcomer strain and/or the acquisition of new information through horizontal gene transfer (Brito, 2021). These are currently being entertained as topics for potential future research projects. I would never have thought about these matters had Lara not been with us – one more case of mutual art-research inspiration.

**A new covenant with nature?**

It looks like the widespread way in which Western culture has dealt with the biological world is, ultimately, based on the mandate of Genesis 1:28 "… Be fruitful and multiply and fill the earth and subdue it, and have dominion over the fish of the sea and over the birds of the heavens and over every living thing that moves on the Earth …" Although the biblical author was unaware of the microbial role played in how life on Earth is sustained, the message was clear that the human mission involves dominance and supremacy over all of the nature that surrounds us. Can this old mandate remain the same forever, though? Reality is that unchecked growth, mostly since the industrial revolution and the Haber-Bosch reaction (Ritter, 2008), has led to a rampaging climate crisis, unmanageable overpopulation, and massive environmental degradation, including growing pollution, and an enormous volume of non-recyclable waste. Some optimists translate such grave issues into merely technical problems that can be met through scientific progress in the hopes that perpetual growth can continue indefinitely. In fact, the dire future anticipated in the famous 1972 book *The limits to growth* has not been realized, owing *inter alia* to the onset of new technologies and scientific discoveries (Meadows et al., 2013). Can this buying of time go on endlessly? Nuclear fusion is presented as the ultimate source of inexhaustible energy (Ongena & Oost, 2004), super-productive transgenic crops are often proposed as the solution to the food crisis (Borlaug, 2000), biofuels the replacement of oil (Solomon, 2010), and biomanufacturing the way to make the production of chemicals more sustainable (Zhang et al., 2017). These are all welcome developments, certainly, but they still fall under the paradigm of unchecked domination of the natural world: changing just the minimum necessary ensures that nothing really changes. Can we ever think otherwise?

Synthetic biology seems to be the battleground for two (somewhat opposing) views of what to do with the wealth of information about the living world that we have amassed over the last 20 years. In one case, the idea of engineering biology aligns with the aforementioned drive to provide robust, effective replacements to our socioeconomic/industrial settings' most undesirable components – but without questioning the system itself (Goven & Pavone, 2015). This approach basically involves genetically programming biological entities to do exactly what we want and for our own exclusive sake (Qian et al., 2018). This looks to me like the ultimate implementation of the aforementioned mandate to "... have dominion ... over every living thing that moves on the Earth ..." Paradoxically, though, synthetic biology is also advanced as a discipline that enables us to enter into a new partnership with nature, owing to our growing capacity to both monitor and decipher – and eventually return – signals that come from the extant natural world (Ananthaswamy, 2014; Lohr, 2021). The question that follows is whether this could make us envision a change in our interplay with the environment – and all life forms that inhabit it, microorganisms included – one not fostered by domination, but in terms of conversation and, eventually, negotiation.

The biggest asset that biological systems have to resist the sheer number of attempts to make them submit is evolution: every successful and durable genetic construct made in the laboratory is, ultimately, a compromise with mutations and constant changes. To this day, evolution is one of the few natural phenomena that we are still unable to make submit altogether. In my opinion, the starting point of our dealings with the microbial world must, therefore, be evolution – something that many think that we understand, but about which we just have scratched the surface in my view (de Lorenzo, 2018). The outcome cannot be anything other than coexistence and compromise. This may look like an extravagant, unrealistic endeavor, but in reality, we are already in the midst of a new way of looking at the biological realm, as exemplified by the contemporary shift in our view of animals in the Western world. For centuries, animals were just edible stuff to either hunt or fish, dangerous foes to avoid/kill, or living objects to tame as a work force, and as non-human companions only to a minor extent. In contrast, our societies are experiencing a growing tendency towards vegetarianism and veganism, respect for animal rights, and sympathy towards feelings that had been thought of previously as being exclusively human. Even animals that were traditionally considered to be entirely non-sentient, such as cephalopods, have turned out to be sort of motile brains that are able to dream, feel, and react to stimuli in quite a human-like fashion (Ryuta et al., 2018; Crook, 2021). Microorganisms are not yet within our scope in that respect, although the role they play in the service of humanity has occasionally been recognized, albeit just symbolically (Metaphorest Aprayer Team, 2022). Microbes were on this planet long before us and they surely have much to tell us, provided we were able to understand their language of course. There is still much to develop in what could be called the microbial world's *attentive epistemology* as a complement of both the standard hypothetical-deductive scientific method and the contemporary emphasis on data-driven research. I believe that art has a big role to play in this endeavor, given that it can grasp features of our interplay with microorganisms that are not yet amenable to formal analyses and can anticipate a new covenant with the natural world, one replete with the forms of life that we cannot see.

Long before modern physics explained the nature of time, space, and matter, various generations of artists explored and reflected upon the same big questions through a diversity of plastic, musical, and literary expressions. It is often argued that impressionism attempted to both capture and echo the energy embodied in the material world by means of effects of light and rough brushstrokes of paint that reflected the inner dynamism of objects and live things in a manner influenced by the progress of the physics of the time. Perhaps a fresh horizon and challenge for the new generation of artists will include apprehending and communicating some of biology's key discoveries from recent decades. First, that all life forms – both visible and invisible – are intimately associated, the apparent gaps among them being effectively filled by environmental microorganisms that act as go-betweens among different manifestations of such a life. Second, that the complex phenomenon that we call 'evolution' rules the interplay between the living world's rationally conscious part (rationality is something that we exclusively claim to be) and the rest. There is still much to do on both the research front and in terms of the cutting-edge artistic creativity, which are bound to walk hand in hand. Who will be the Monet, Renoir, or Cézanne of our times? What discoveries will have inspired them?

# BIBLIOGRAPHY


01. Abraham, A., & Jain, L. (2005). Evolutionary multiobjective optimization. In *Evolutionary multiobjective optimization* (pp. 1-6). Springer, London.
02. Ahmad, H. I., Ahmad, M. J., Asif, A. R., Adnan, M., Iqbal, M. K., Mehmood, K., Muhammad, S. A., Bhuiyan, A. A., Elokil, A., & Du, X. (2018). A review of CRISPR-based genome editing: survival, evolution, and challenges. *Current Issues in Molecular Biology,* 28(1), 47-68.
03. Ananthaswamy, A. (2014). Rewiring Nature With Synthetic Biology. *Discover Magazine.* https://www.discovermagazine.com/technology/rewiring-nature-with-synthetic-biology.
04. Blaser, M. J. (2014). The microbiome revolution. *The Journal of clinical investigation*, 124(10), 4162-4165.
05. Borlaug, N. E. (2000). Ending world hunger. The promise of biotechnology and the threat of antiscience zealotry. *Plant physiology*, 124(2), 487-490.
06. Brito, I. L. (2021). Examining horizontal gene transfer in microbial communities. *Nature Reviews Microbiology,* 19(7), 442-453.
07. Cases, I., & Lorenzo, V. d. (2005). Genetically modified organisms for the environment: stories of success and failure and what we have learned from them. *International Microbiology* 8(3): 213-22.
08. Crook, R. J. (2021). Behavioral and neurophysiological evidence suggests affective pain experience in octopus. *iScience,* 24(3), 102229.
09. de Lorenzo, V. (2008). Systems biology approaches to bioremediation. *Current Opinion in Biotechnology,* 19(6), 579-589.
10. de Lorenzo, V. (2014). From the selfish gene to selfish metabolism: revisiting the central dogma. *Bioessays,* 36(3), 226-235.
11. de Lorenzo, V. (2017). Seven microbial bio-processes to help the planet. *Microbial Biotechnology,* 10(5), 995.
12. de Lorenzo, V. (2018). Evolutionary tinkering *vs.* rational engineering in the times of Synthetic Biology. *Life Sciences, Society & Policy,* 14: 18.
13. de Lorenzo, V., Marliere, P., & Sole, R. (2016). Bioremediation at a global scale: from the test tube to planet Earth. *Microbial Biotechnology,* 9(5), 618-625.
14. Dvořák, P., Nikel, P. I., Damborský, J., & de Lorenzo, V. (2017). Bioremediation 3.0: engineering pollutant-removing bacteria in the times of systemic biology. *Biotechnology Advances,* 35(7), 845-866.
15. Edmonds-Wilson, S. L., Nurinova, N. I., Zapka, C. A., Fierer, N., & Wilson, M. (2015). Review of human hand microbiome research. *Journal of Dermatological Science,* 80(1), 3-12.
16. Environmental Synthetic Biology Laboratory (2022). Victor De Lorenzo's Lab. https://vdl-lab.com/
17. Foster, J. A., & Neufeld, K.-A. M. (2013). Gut–brain axis: how the microbiome influences anxiety and depression. *Trends in Neurosciences,* 36(5), 305-312.
18. Foster, J. A., Rinaman, L., & Cryan, J. F. (2017). Stress & the gut-brain axis: regulation by the microbiome. *Neurobiology of Stress,* 7, 124-136.
19. Goven, J., & Pavone, V. (2015). The bioeconomy as political project: A polanyian analysis. *Science, Technology, & Human Values,* 40(3), 302-337.

20. Hoyt, A. (2021). Do people and Bananas really share 50 percent of the same DNA? How Stuff Works. Retrieved October 3, 2022 from https://science.howstuffworks.com/life/genetic/people-bananas-share-dna.htm.
21. Ko, Y.-S., Kim, J. W., Lee, J. A., Han, T., Kim, G. B., Park, J. E., & Lee, S. Y. (2020). Tools and strategies of systems metabolic engineering for the development of microbial cell factories for chemical production. *Chemical Society Reviews,* 49(14), 4615-4636.
22. Lohr, S. (2021, November 23). Can Synthetic Biology Save Us? This Scientist Thinks So. *The New York Times*. https://www.nytimes.com/2021/11/23/business/dealbook/synthetic-biology-drew-endy.html
23. Madonna Project (2022). Madonna Project Website. https://madonnaproject.eu/.
24. Malik, G., Arora, R., Chaturvedi, R., & Paul, M. S. (2021). Implementation of genetic engineering and novel omics approaches to enhance bioremediation: a focused review. *Bulletin of Environmental Contamination and Toxicology*, 108(3):443-450
25. Martínez-García, E., & de Lorenzo, V. (2017). Molecular tools and emerging strategies for deep genetic/genomic refactoring of Pseudomonas. Current *Opinion in Biotechnology,* 47, 120-132.
26. Meadows, D. H., Randers, J., & Meadows, D. L. (2013). The Limits to Growth (1972). In *The Future of Nature* (pp. 101-116). Yale University Press, New Haven.
27. Metaphorest Aprayer Team (2022). *aPrayer: memorial service for microorganisms and artificial cells and lives*. https://hideo-iwasaki.com/aprayer-microorganisms.
28. Ongena, J., & Oost, G. V. (2004). Energy for future centuries: will fusion be an inexhaustible, safe, and clean energy source? *Fusion Science and Technology,* 45(2T), 3-14.
29. Payne, J. L., & Wagner, A. (2019). The causes of evolvability and their evolution. *Nature Reviews Genetics,* 20(1), 24-38.
30. Qian, Y., McBride, C., & Del Vecchio, D. (2018). Programming cells to work for us. *Annual Review of Control, Robotics, and Autonomous Systems*, 1, 411-440.
31. Ralser, M., Varma, S. J., & Notebaart, R. A. (2021). The evolution of the metabolic network over long timelines. *Current Opinion in Systems Biology,* 28, 100402.
32. Ritter, S. K. (2008). The Haber-Bosch reaction: an early chemical impact on sustainability. *Chem Eng News,* 86(33), 53.
33. Rylott, E. L., & Bruce, N. C. (2020). How synthetic biology can help bioremediation. *Current Opinion in Chemical Biology*, 58, 86-95.
34. Ryuta, N., Shuichi, S., Letizia, Z., Fabio, D.S., & Schmidt M. (2018). Cephalopods between science, art, and engineering: A contemporary synthesis. *Frontiers in Communication,* 3(20), doi: 10.3389/fcomm.2018.00020.
35. Sandberg, T. E., Salazar, M. J., Weng, L. L., Palsson, B. O., & Feist, A. M. (2019). The emergence of adaptive laboratory evolution as an efficient tool for biological discovery and industrial biotechnology. *Metabolic Engineering,* 56, 1-16.
36. Schmidt, M., & de Lorenzo, V. (2012). Synthetic constructs in/for the environment: managing the interplay between natural and engineered Biology. *FEBS Letters,* 586(15), 2199-2206.
37. Solomon, B. D. (2010). Biofuels and sustainability. *Annals of the New York Academy of Sciences,* 1185(1), 119-134.

38. Stewart, C. J., Ajami, N. J., O'Brien, J. L., Hutchinson, D. S., Smith, D. P., Wong, M. C., Ross, M. C., Lloyd, R. E., Doddapaneni, H., & Metcalf, G. A. (2018). Temporal development of the gut microbiome in early childhood from the TEDDY study. *Nature,* 562(7728), 583-588.
39. Swiss Institute of Bioinformatics. (2020, December 16). The DNA regions in our brain that contribute to make us human. *ScienceDaily*. Retrieved October 3, 2022 from www.sciencedaily.com/releases/2020/12/201216085039.htm.
40. Talbott, S. M., Talbott, J. A., Stephens, B. J., & Oddou, M. P. (2020). Modulation of gut-brain axis improves microbiome, metabolism, and mood. *Functional Foods in Health and Disease,* 10(1), 37-54.
41. Wagner, A. (2017). Information theory, evolutionary innovations and evolvability. *Philos Trans R Soc Lond B,* 372(1735), 20160416.
42. Wolpert, L. (1994). *The unnatural nature of science*. Harvard University Press, Cambridge Massachusetts.
43. Zhang, Y.-H. P., Sun, J., & Ma, Y. (2017). Biomanufacturing: history and perspective. *Journal of Industrial Microbiology and Biotechnology,* 44(4-5), 773-784.

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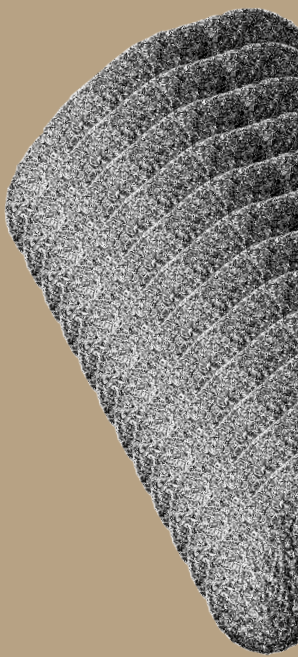

# LEE CRONIN –

## THE CRONIN GROUP AT THE SCHOOL OF CHEMISTRY

Research in the Cronin Group at the University of Glasgow is motivated by the fascination for complex chemical systems, and the desire to construct complex functional molecular architectures that are not based on biologically-derived building blocks.

# ISABELLE ANDRIESSEN

Isabelle Andriessen is a visual artist. She researches ways to animate inanimate materials in order to create ‘performative’ sculptures. These sculptures transform physically along their own agency, metabolism, and behavior – over the course of one or several exhibitions.

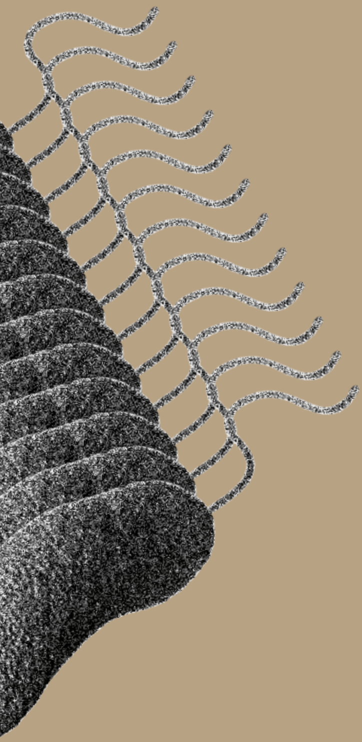

fig. 3.11 The self-replicating microorganisms *Escherichia coli* and *Pseudomonas putida* are bacteria strains used to implement new-to-nature reactions.

# SOULS FROM THE DEEP: A SURVEY THROUGH A STICKY UNIVERSE

by Isabelle Andriessen

We live in a time in which the earth's system is highly disrupted; biotic and abiotic components are merging, due to the synthetic materials and toxicities which we allow to spill into our environment, like oil, lithium, plastics, hormones, and chemicals that do not decompose – leading to more and more life forms that can endure increasingly extreme climates. In the face of this daunting new material reality, I envision resilient and unsettling specimen or entities that reside in the interface between the human and non-human, the living and non-living.

I investigate ways to physically animate inanimate materials in order to provide them with their own metabolism, behavior, and agency through both my sculptural work and material research. In so doing, these works become agents that inhabit a liminal space between sculpture and performance, composed of synthetic materials that both act and evolve, seemingly beyond control and often irreversibly. Deriving their anatomies from science-fiction and scientific narratives, these alien animatronics are 'sticky' and 'fluid' life forms. They continuously creep, ooze, and spread. My sculptures can be read as future fossils evolving and enduring an environment under severe pressure. They also make for an uncanny landscape, as if infected by a strange virus.

My artistic practice is driven by the paradox between the beauty of transformation and the continuous loss inherent within it, which is both material and perceptual. I force ceramics, aluminum, wax, silicon, and plastics to react to heat, cold, chemicals, or electricity so that the materials start to interact, crawl, grow, sweat, and move. The underlying motivation is to obscure and to stretch the boundaries between what we call living and non-living materials. It is exactly this agency, which is imposed on my work, that showcases the passage of time and makes the sculptures resemble eerie performers.

This project began in 2016 with *Resilient Bodies*[1], a series of ceramic, fossil-like shapes that are heated by electricity to a temperature of 80°C, thereby causing the wax and plastic forms to melt and deform. The materials transformed and morphed over the course of the exhibition into scrap leftovers, leaving a sticky pool in which the sculptures seemed to bathe.

*Tidal Spill* [2](2018) is a series of four ceramic sculptures from which crystals grow on the surface over the course of several exhibitions. The sculptures' insides contain different chemical solutions that are being absorbed by the ceramic skin, leaving it to crystalize over a period that can take years. Their skin-like ceramic surfaces display signs of fever, tumors, and rashes as if the sculptures are contagious.

A more parasitical relationship becomes evident in *Terminal Beach* (2018), which consists of three large-scale ceramic sculptures, from which chemical crystals also grow on the surface over time. The sculpture contains an iron II sulphate solution that is being absorbed by the ceramics, leaving it to crystalize over a long period. Sweating aluminum 'braces', which are connected to a system that cools the aluminum down so that it absorbs moisture from the air, is also mounted onto these sculptures. This moisture is then collected by the sculptures, feeding the growth of the crystals over a long period of time in the process.

My latest production is *DORM* (2021), a series of sculptures that aims to reveal the uncanny nature of synthetic materials. This large-scale solo exhibition consisted of three works: *Necrotic Core*, *Bunk Beaks*, and *Idle Knights*. These pieces actively address negative space, thereby straddling the line between automata and mineral concoctions, between futuristic machines and cybernetic systems. The title refers to a 'dormitory', a room, or a kind of cell in which a collection of bodies can be restored, in order to carry on with their functional duties. The term 'dorm' also comes from the word 'dormant', which is the physical state of being asleep or inactive. Something that is dormant is unasserted, inactive, or growing but with the imminent possibility of suddenly being awake. These two definitions strangely merge through a dark and hidden interaction: a room in which entities exchange air, perspiration, and other metabolic access.

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[1] Documented at: https://gallericc.se/Isabelle-Andriessen

[2] All other works referenced throughout the text are documented at the artist's website: https://www.isabelleandriessen.com/work/

Each of these works obviously derives from a new strand of material research. Even though I have been working with scientists since 2016, I have still not found a way to successfully apply material innovations into my sculptural practice. I reached out to Dr. Lee Cronin because I wanted to learn more about his approach to living and non-living materials at the beginning of 2020. I was curious about how he was developing self-organizing synthetic materials and if this knowledge could be applied in the field of sculpture. He invited me to apply for the Biofaction residency shortly thereafter, so that I might collaborate with him and his team on my artistic research. We then met online in May of that same year. During our conversation, we discussed the parameters that he uses to look for new definitions of life.

My initial motivation to apply for the residency was to develop a new set of synthetic materials that would physically animate, deform, or reform over the course of time, while being applied to a new set of sculptures. I aimed for the collaboration to result in sculptures that consisted of materials that require electrical and chemical interventions to maintain their transformation into a semi-living state; this was so that I could make them behave like weird organisms of a speculative future, and which when combined form an otherworldly and parasitical ecosystem that develops in an autonomous and unpredictable way, as if infected by a strange virus or illness causing entity.

The proposal's underlying motivation was to address plausible speculations for new life forms to arise from a toxic environment, much like that of hydrothermal vents, e-waste sites, or lithium mines. The new 'life' forms depend upon the power of (chemo)synthesis or 'alien' synthesis in order to evolve into living matter from the waste left behind. What life forms may inhabit our Planet in the future? How would this semi-life fuse, adapt, or mutate alongside these disregarded (plastic) remains, and create digestive systems or anatomy? What if evolutionary roads take us to entities that can live off of e-waste?

In the early stages of my contact with Cronin, I imagined the outcome of his research to be in a much more physical or material stage than actually feasible in real life. Over time, I learned that the Cronin Group is researching and developing materials on a molecular scale, oftentimes only visualized in mathematic equations and, if you are lucky, recorded in petri dishes. The Cronin Group's research scope is vast and very abstract. It contains some level of 'living' material, but it is more based on mathematics and molecular science. Developing materials on a microscopic level, however, is not my preferred medium, given that the bodily encounter with the time-based sculptures is a crucial element in my work.

This condition forced me to review how this collaboration would translate into a narrative that could be used as a basis for my research and upcoming projects. Therefore, I decided to focus on finding entry points into the more sublime aspects of Cronin's research by zooming in on specific aspects through the materiality of film. In so doing, I aimed to capture a (potential) lifeform as it developed over time in the lab. How were they looking for life, animating life, or revealing material agency?

When we first met, Dr. Lee Cronin had started to conclude on his principle and mathematical equation concerning self-assembly. The self-assembly theorem is a breakthrough formula to prove natural selection mathematically. Cronin was formulating the self-assembly theory as a method to trace back the origins of life that is encoded (or stored) in each material. Assembly theory compares how complex a given object or material is as a function of the number of independent parts or molecules. A given fact is that living materials have a much higher level of complexity than non-living materials. In short, the equation of self-assembly proves natural selection, which can give us a lot of insight into the development of life in other Earth-like systems.

The Cronin Group is also working with widely used instruments to develop, what they call, the self-assembly index: a parameter to detect bio-signatures – chemicals that point to living systems. This is a revolutionary approach that is useful in investigations of (alien) material obtained during space expeditions, in order to measure if the same material also appears on our planet and what range of evolution took place prior to the formation of the material's molecular compound, for example. Different teams are collaborating on building 'chemputers' that would be able to build living materials from chemical, non-living materials. These 'chemputers' can also be applied to 'print' drugs or other on-demand medical needs. A part of the team is also working on downscaling these 'chemputers' so that they can easily be installed in space expeditions.

Cronin and his research team are creating artificial life forms from non-biological chemistries that mimic the behavior of natural cells in an attempt to understand how life itself originated from chemicals. These chemical cells are called 'Chells'. Despite our research questions overlapping in many ways, our approaches and results are completely different. They are trying to formulate and to catalogue overlapping parameters that define what the signatures of life are with the help of measurement instruments like Mass

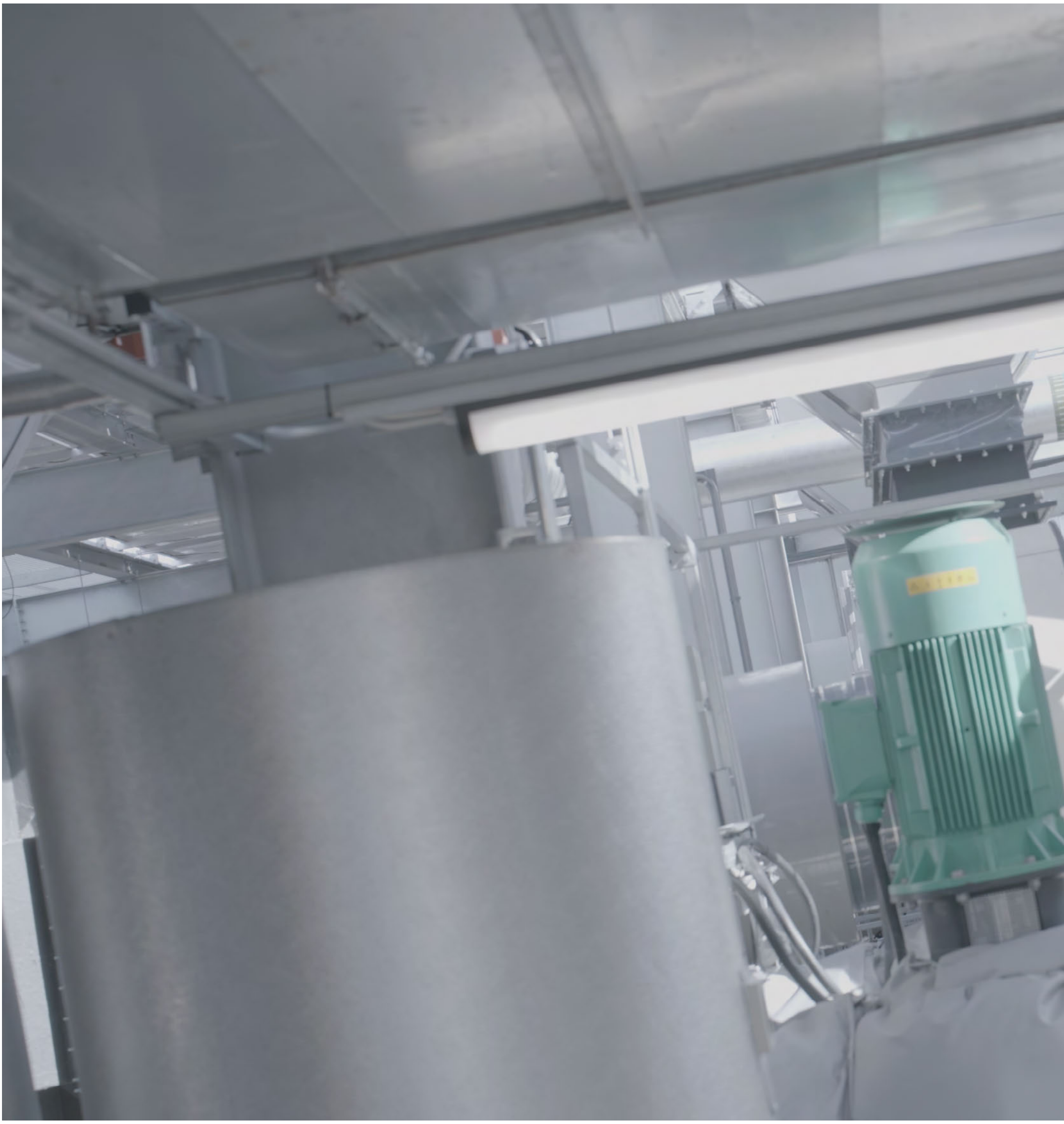


fig. 3.12 Film still.

and NMR spectrometers, as well as ICP. This information will serve as the basis for future research on identifying extra-terrestrial life forms.

My decision to translate this residency's research into film is especially fitting because it allowed me to express my translations of scientific narratives into another medium than sculpture. A reoccurring aspect of my work is the notion of worldbuilding, given that each individual sculpture anticipates its own imaginary narrative, influenced by scientific knowledge. I think the Cronin group's abstract theories are a lot harder to fathom in sculpture, because of their rather mathematical and molecular nature.

During my working period, I anticipated being able to capture these grim outcomes by tracing the behaviors and agency currently happening in the labs. The result of this is an uncanny surrealist science-fiction film, in

fig. 3.13 Film still I.

which the Cronin Lab functions as an environment or a landscape in which the film's narrative unfolds. I aimed to develop a project that allowed for Cronin's research to be able to become a more tangible experience for the viewer. As a result, this film's material is partly taken from the research lab and has been combined with CGI animation.

What would happen if these instruments in the lab were left running, of their own accord, either on our own planet or left behind after a space expedition? What if these 'chemputers' got hacked or controlled by a virus or immortal cell mutation? What is the dystopia contained within these processes? In what ways could the self-assembly theorem, as formulated by Lee Cronin, influence future life forms, and how would they emerge? Can synthetic materials develop memory and consciousness? I believe that it is this

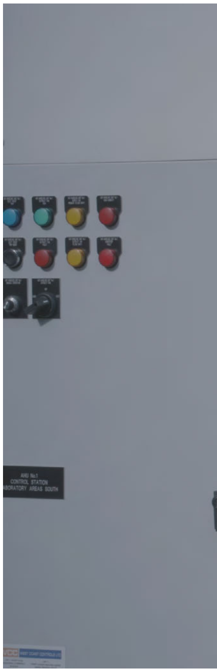

AHU No.1
CONTROL STATION
ABORATORY AREAS SOUTH


fig. 3.14 Film still II.

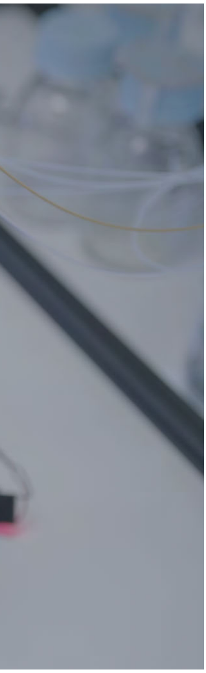


fig. 3.15 Film still III.

friction, or this space addressed by this friction, where the sublime aspect of Cronin's theories can creep under the skin.

In the film, the Cronin Lab is a seemingly abandoned place in which 'chemputers' are up and running at full speed. It is on the verge of an apocalyptic event, or perhaps this had just happened recently. Throughout the film, a voice-over narrates fragments of different events. Eventually, it is likely that this voice is also that of the protagonist – an automata – calibrating the sequence of events and navigating its surroundings and finding its way in this abandoned place, piecing what happened previously back together.

What it is that they are doing remains unclear. Other 'chemputers' operate inside the lab, attempting to communicate with aliens and other non-human entities. An alternative life form is being developed by the automatic instruments in the lab. The film sustains a slow-paced level of suspense.

The research team and surrounding staff members were very welcoming and helpful throughout the entirety of the residency. I greatly appreciated their openness and the fact that everyone seemed to be comfortable having me there. Many of them were eager to show me how they operate their research in the 'chemputers', both 'on' and 'off' set. Without their time, patience, and enthusiasm, I could not have been able to produce this film. In the end, the 'chemputers' turned out to be major actors in this film. I was very impressed with the amount of information they entrusted me with, given that what the team is working on is highly confidential. Since I do not have a scientific background at all, I relied on them to explain their knowledge in a rather basic way, yet it felt like I was able to engage in their research on an abstract level.

Needless to say, I am in awe and have nothing but respect for the research conducted by Lee Cronin and his team. I worked with a number of researchers over the course of the residency and I found working with the Cronin Group really rewarding and enriching. I am extremely impressed with the level of operation, and how this is all managed and directed by Lee Cronin. His scientific and business strategies are very inspiring and, to me, even revolutionary. For this reason, it was amazing to finally, after two long years, work in the Cronin Group's research lab. Even though I collected as much visual and theoretical material beforehand as possible, it is hard to imagine how the 'chemputers' and all of the different engines function. I was blown away by the scale of the laboratory.

The collaboration with the Cronin Group occupies the heart of this film project, yet I also collaborated with a team of specialists from different fields. For this reason, the residency did not begin from the moment that I arrived in the research lab. Prior to my arrival in Glasgow, I spent a considerable amount of time with a selection of essays, interviews, and general (and advanced) introductions to the Cronin Group's material research and ambitions.It was crucial for me to understand the bigger picture, not just to understand how the team and their tools/engines are structured, but also what the ambitions, the driving force, long-term goals, and benefits are.

Upon my arrival, I met the different research teams individually. By doing so, I could get a better sense of what each team was responsible for as well as how they collaborated. In the days that followed, I joined Dr. Lee Cronin and the different teams in their meetings, presentations, and discussions. During the week that I was present, I got sufficient insight into their research to know how to include it in the film. In the second week, Clemens Stump (scenographer and camera man) arrived so we could get started with the actual filming. Prior to his arrival, we had worked on the cinematography, light design, and location scouting within and around the research lab. During the filming process, we focused on the visual output, functions, and behavior of the 'chemputers'. An important question was: is it possible for the camera to capture these different processes, following them and recording them fully?

In relation to this, we rented the recently released DJI Ronin 4D camera, which was a big investment. Since it was not available in Glasgow, we had to bring it from the Netherlands, which limited the amount of time in which it was possible to film and experiment. Nevertheless, it was worth the investment, as the results really conveyed the non-human camera movement that we were looking for. The camera films in 8K, and its most special feature is the 4 axes lens that can be directed to move around robotically/mechanically. In this way, the lens moves around like a robot or automatic non-human entity, and inevitably, this is crucial for the viewer's non-human perception/experience.

I would have appreciated, if I had had the chance to be in direct contact or conversation with Dr. Lee Cronin, but I estimated that it was also an unprecedented busy period for him and his team. Due to COVID-19, he and his team were mainly working from home, and on top of that, he had to transfer his entire laboratory to another building, while at the same time setting up the Chemify company. Another challenge to the process was the fact that the research lab is located in a non-EU country, forcing me to wait for the permission to travel until corona travel measurements were abolished.

Then, when it was finally possible, Dr. Lee Cronin was in the process of moving his entire research lab, which caused subsequent delay.

In order to introduce my artistic approach to the Cronin Lab's research group upon my arrival, I gave an online lecture to the lab team in August 2020. However, I wondered if it would have been more helpful to have given a shorter and more visual introduction to my practice and residency proposal. For some reason, I sensed a lack of interest in my work from the scientists, although they were highly cooperative. During our conversations, neither Dr. Lee Cronin nor any of the other scientists asked about my practice. It is really a pity that the exchange between us seemed only one-sided, while it could easily have been an enriching interaction for the research group, as well. The reason might be that contemporary art was not so much in their scope of interest or maybe the majority of scientists had a very rationalistic approach to material and information and, therefore, they could not relate to my way of working. I cannot really grasp the reason for this disinterest, although I can imagine that my practice seemed as abstract to them as theirs did to me.

I think that the hardest part of this project is that instead of having two years to work on it, I only had a couple of months to develop the entire working material and to turn that into a final product. Throughout this period, I had very little or no response from Lee Cronin, nor any leads or follow-ups from him or his team members. This resulted in a lack of a sense of collaboration or exchange, with the exception of the dialogue that I established with the material I found about his research online. At the same time, I put a lot of effort into searching for fundraising options for the project, through sponsorships from other foundations – the allocated funds from Biofaction's stipend could not, by any means, cover the expenses of making a high-quality film production. I am proud to say I have succeeded in this and that this project is now a co-production, with a fifth of its budget being covered by Biofaction, and the rest by Amarte Foundation and Stimuleringsfonds.

These two months were really challenging, given that this residency is the start of a much larger production; it was the most unrealistic request I have ever tried to live up to, but me and my team are striving to complete this film production, even if it takes non-human powers to do so.

Within the production of the film my roles are mostly that of being the (art) director, scenographer, and scriptwriter. I am also working alongside a major group of artists: Clemens Stump (cinematographer no. 1 and co-producer) who also acted as camera man in this project, Nikola Lamburov (photographer and cinematographer no.2), Becket Flannery (play writer 1), Valerian Gago Beaufour (assisting editor and sound designer), and Marian

Rosa Bodegraven (production manager and assistant). These people are mostly involved with the featured aspects of the film. The CGI animation will be developed by a group of (game) designers that are skilled in programs like Unity and Blender. Again, this project proves that my work is made by many hands, always seeking for the potential that lies in collaboration.

Concluding on my residency, and having had the chance to process all of the information and findings, I am thrilled about the fact that we, humankind, continue to be surrounded by the unknown, no matter how many decades we have evolved alongside technology, no matter how much we can reveal or measure. The more we zoom in on these molecular identities, the more complex life turns out to be. This makes me wonder; will we be stuck with these unknown entities and agency – aliens – forever? These aliens in our bodies, on our skin, in our phones and computers, our architectural systems, our oceans, in the sky and air. What if the alien is so alien that one might not even recognize it as such?

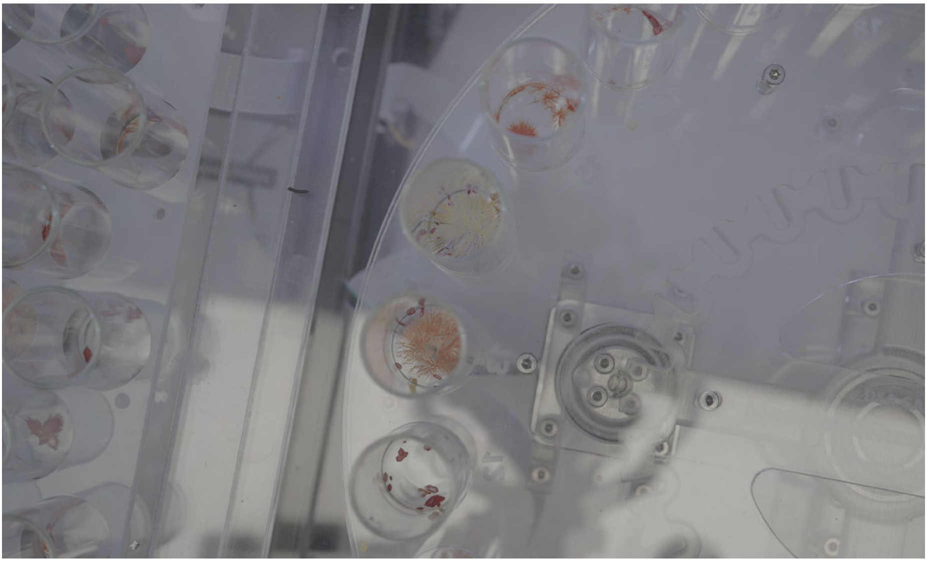


fig. 3.16 Film still IV.

The trailer of the film is available at the following link:
https://vimeo.com/723349549

# BREATHING LIFE INTO INORGANIC ALIEN MATTER

by Lee Cronin

Our laboratory was established at the University of Glasgow in 2002 as the complex chemical systems laboratory. I was appointed to the Regius Professor of Chemistry in 2013 and today my team is one of the world's largest chemistry-focused research teams.

I have wanted to explore chemistry using electronics to control matter since the age of 9 when I got a ZX81 computer and a chemistry set and after becoming frustrated that I could not connect them together. This is because I wanted to understand how to control matter from the bottom up. Ever since I could remember, I have been interested in understanding why we are here, why life exists, and what life is. It seems to me that there is a fundamental disconnect between our understanding of fundamental physics, chemistry, and biology; this is because these systems become more and more complex the further you get from physics to biology. However, many physicists, anxious not to lose the complexity bandwagon, also got involved in the area of chaos theory which highlighted to me that classical physics, as well as quantum mechanics, suffered from uncertainty. When I was 18 years old, I became convinced that the one big problem that needed to be solved was figuring out how life started on earth. Put literally: how does the dead or inorganic world become living? How is sand transformed into cells? Today, my entire research team is set up to explore this grand aim.

I made a number of observations when I was setting my team up to look at the search for the origins of life, or how to make life from scratch in the laboratory. First, I reasoned that the origin of life is in fact a 'big chemistry problem'. The issue is that doing experiments by hand in the laboratory was going to be hard; the origin of life also appeared to require a lot of experiments. It is thought that life emerged 'quickly' on earth, perhaps in less than one hundred million years. That would require a lot of chemistry experiments! A radical solution was needed to address this problem: we needed to digitize chemistry. To address this moonshot, we built the team around four main aims: the construction of an artificial life form; the digitization of chemistry; the use of artificial intelligence in chemistry including the construction of 'wet' chemical computers; and the exploration of complexity and information in chemistry. Our recent work on the digitization of chemistry has resulted in a new programming paradigm for matter and organic synthesis and discovery – chemputation – which uses the world's first domain-specific and universal programming language for chemistry – XDL[1]. My team designs and builds all of their own robots from the ground up and the team currently has 25 different robotic systems operating across four domains: organic synthesis, energy materials discovery, nanomaterials discovery, and formulation discovery. All of the systems use XDL and are easily programmable for both manufacturing and discovery. My group is organized and assembled transparently around ideas, avoids hierarchy, and aims to mentor researchers that use a problem-based approach. Nothing is impossible until it is tried.

My role in the Madonna project involved the construction of digital-chemistry-robots that could discover new reactions for biological systems and to engineer ways of embedding these new reactions in biological systems. The idea here was to find the correct language to allow the robots, chemical, and biological systems to interact with each other. The language of biology is not only genetic, but kinetic and spatial. The language of chemistry is molecular, with concentrations and kinetics, and the language of robotics is digital programming. Interfacing these systems together was one of the Madonna project's biggest challenges.

I was very happy to host an artist in my laboratory as I thought it would be a good way to communicate the efforts going on in the laboratory, the big picture, and the way science is done across big teams that are unified by a single grand vision. The artist, Isabelle Andriessen, first gave an online lecture to our group about her work and we had a discussion about the teams' work before her arrival. When she visited, she interviewed me several times and also spent time talking to various members of my team finding out about their research, exploring the robotics, looking at data, the architectures of what we were building, and so on. This was helpful as a very

[1] For more info, you can visit: XDL-standard.com.

important aspect would be that the artist could help to develop a common language or visual that would capture the vision and allow both the team and the outside world to see how we are exploring the problem of making a new life form. The first question that we had to understand was perhaps even harder than aiming to make life: What is life? I mean, really, what is life – we all think we know it when we see it, but do we? A key issue is that if you ask 10 people to define life, then you will get at least $10^2$ answers as a point-by-point list of vital characteristics. This narrative does not lend itself to a well-contained argument. To solve this, we have managed to find a way to define life by finding a unique thing that all living things do – but could I explain this to anyone, and could this be captured for the non-scientist?

The key insight that I needed to explain, as a chemist to a non-chemist, is that life, or living systems, have the unique ability to make complex molecules in large amounts. The focus on the molecules is good since if living systems can make molecules so complex that they could not possibly form by chance, then could we make a complex molecule detector? Would this be a life-detector? We have developed a new approach to counting molecular complexity by using a machine called a mass spectrometer in order to rank how complex a molecule is. A mass spectrometer can weigh the molecule and can tell you how many unique parts it has; it is also possible to count the total number of molecules.

Now that we have a life-detector, can we now build an origin of life, or artificial life, 'search engine'? This is the main project that is underway in my lab at present. We are literally designing one of the biggest and longest chemistry experiments ever planned. The system will be able to search trillions upon trillions of reactions, looking in many different environments, but will we find the spark of life? It was great that Isabelle visited our laboratory during the design and building phase of the experiments.

My own background in art is on the visual side, where I spend a lot of time developing ways to explain our ideas and approach. This can take the form of technical drawings, conceptual diagrams, and movies. As a hobby, I have even explored encoding imagery into digital oscilloscope art and composing music inspired by our science. This art is very dynamic because the pictures are encoded into the music, so the pictures emerge and are dynamic when the waveform is plotted by the oscilloscope. I was very interested to compare and contrast this approach with the artist. To my surprise, I found my approach more 'emotional', exploring a creative space with not too much meaning whereas I found the approach of the artist to be also emotional, but with much better methods and also a clearer set of intentions. This intentionality is exciting since it will ensure that the artist is able to explicitly encode a lot of meaning into the art being produced. I am also excited because I think the use of interpretive art as a medium to convey science ideas, new findings, theories, and questions is highly important and has the potential to widen participation and to inspire the imagination.

The artist, Isabelle Andriessen, visited our laboratory as we were designing and building our robotic laboratory for the exploration of the origin of life/the discovery of artificial life. My team moved into the new Glasgow Advanced Research Centre in February 2022. This is the biggest purpose-built facility for digital chemistry in the world and houses a vast array of robotic equipment and state-of-the-art chemical analysis tools. The residency was tough to set up because of our conflicting schedules coming out of COVID-19, but we were able to develop an interesting set of ideas that explored the possibilities of using a combination of online and real time visits. The artist shadowed part of my team and conducted interviews asking team members about their research, aims, and expectations.

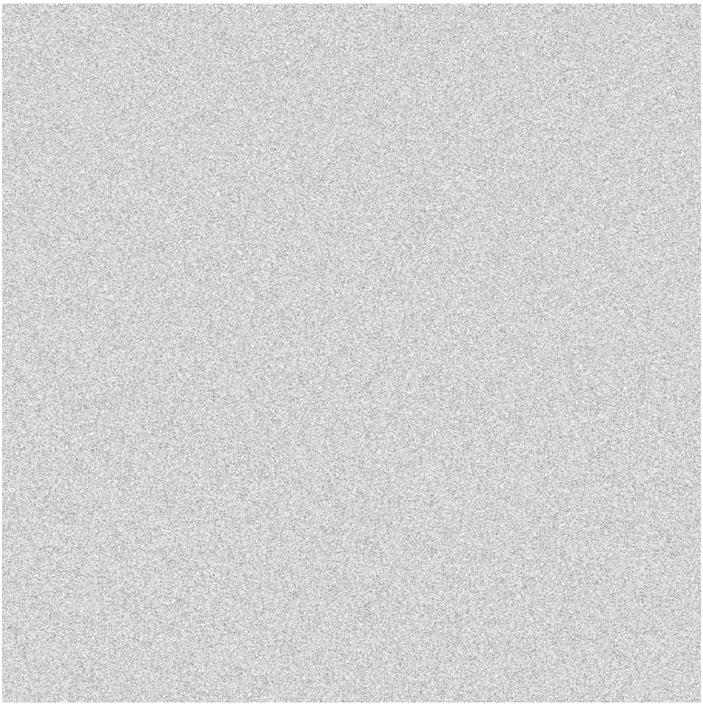
I think that the collaboration with Isabelle was amazing because her interest in the re-animation of dead materials and understanding the death-to-life transition was a key overlap between us. I think that her views on the nature of this critical transition – what happens when the living becomes dead and when the dead becomes living is a critical question for science and more generally culture. What happens to living information after it dies? Does it disperse? Is it lost? Does the information created in one life live on in others? The initial creation, a movie, and a narrative about the robotics in the laboratory searching life, the prospect for life conveys the mystery and the expectation of the discovery.

My view of the process was that it was extremely dynamic. Although I only spent a limited amout of time with Isabelle, I found that my feelings and anticipation of the discovery, the meaning of the research, and the bigger picture were reflected in the encounters we shared. It was almost as if we had swapped roles, with me being the artist interpreter of the science, and Isabelle being the scientist questioning the world. This reflective interaction is something that I like to do in science because reality is not some fixed or some static quantity; reality is shaped by our interactions with each other, with the world, and is also modulated by our sensors and views or biases.

Now that the visit is over, I am excited to see the outcome, but I am also mindful that Isabelle was only with us for such a short time and that our project is still going. The short film produced is very powerful in terms of the visuals, the narrative, and the way in which the heartbeat of the laboratory was captured. It made me feel that the experiments and the animation via the robotics was starting to breathe life into the inorganic robots.

Will we manage to build a new lifeform from scratch anytime soon? Could this event be captured and explained by future interactions with artists-in-residence? Should we attempt to document, explain, and engage with the public through expressions of art? I think that the answer to all of these questions must be yes. Understanding the process of life is vital, if we are ever going to understand if there is life elsewhere in the universe, to understand the origin of life on earth, and also to understand the future of life on earth, humanity, and our culture.

# AFTERWORD



# FRICTION GAINS IN ART AND SCIENCE COLLABORATION: MORE THAN NOISE

by Claudia A. Schnugg

Introducing art and science collaboration to new audiences can raise some eyebrows. First, why would a person want to do this? Second, art and science are vast terms, so this could involve anything. What does it involve and how might the outcome be interesting? In other words, *is all of this work (with no definable outcomes to speak of) just all noise?* Are all of these experiences, semi-structured inspirations, and outcomes (in-between the fields of art and science) more than noise that we should bother with? In this chapter, we will explore these questions in terms of 1) the overall concept of art and science collaboration, 2) from the perspective of the actors in the process, and 3) with a final view on the outcome.

**To mingle and to make noise**

This book's beauty is that it brings together the most recent series of Biofaction artist-in-residence initiatives. These four artists were provided with the opportunity to work within a selection of scientific projects in synthetic biology, thereby demonstrating the diversity of scientific work even within the discipline of science. Molecular biologists, geneticists, chemists, and other disciplines came together to work on projects in synthetic biology. In so doing, each group of scientists had the opportunity to seize upon a valuable and even impactful collaboration with an artist. Conversely, we see huge diversity in the collaborating artists' artform and artistic practices that were brought to the collaboration: musical composition, sculpture, photography, film, and visual arts employing various media. Breaking down the boundaries of disciplines and inviting joint exploration, research, and production between the arts and sciences has been realized as a rich experience in many constellations of artists and scientists. To that end, any art and any science can be involved – including engineering and technology. Thus, art and science collaboration can be understood through a more general term or method such as 'transdisciplinary'. Traditionally understood as 'transdisciplinary', because art goes beyond academia, thereby fusing these diverse forms of knowledge, but also opening the potential to connect to audiences. In collaborations in which artists and scientists investigate together, the arts can also be understood as another discipline, a field of knowledge production with its own set of methods. Thus, the term 'interdisciplinary' is also sometimes used in this context.

Bringing art into the mix is about more than adding another scientific/academic discipline; it also involves more than just adding an expressive craft to the execution of ideas. Artists can look at complex issues from the perspective of their strong artistic research processes. They also relate to a diversity of forms of knowledge in their artistic research process through which they add complex contexts that other disciplines traditionally are not in the habit of including. Moreover, the arts' strong foundation in aesthetics, aesthetic investigation, aesthetic understanding of processes, and aesthetic expression are precious contributions to collaborative processes, insights, and outcomes.

**Friction gains**

I will first introduce some general thoughts, and then link some of these to the examples of the four art-science pairings as presented in this book in order to explore why engaging in such a complex thing as bringing together art and science, and investing time in the process of artists and scientists working together, is worthwhile.

Stories of mingling art and science are also stories of frictions. Friction is something that frequently rings alarm bells for engineers and managers. As a technical term, friction in engineering can pose challenges to the constructions or can affect either a machine's materials or moving parts. Friction in economic terms can be interpreted as extra time, energy, and money needed, which often boils down to additional costs.

What is the merit, then, in speaking positively about friction in stories of art and science collaboration? Friction can, for example, arise when an artist and a scientist come together and have completely different ideas about what an interesting research question would be; friction can emerge from problems in communication, the artist meaning one thing, the scientist understanding something different; or friction can be caused by additional obstacles in an organization such as special permissions and bureaucratic requests, changing routines, or adjusting to another person's habits. Moreover, friction implies additional learning processes or skills needed, or changing pre-determined routes into something that connects more deeply with the given environment, or even critically challenging one's own perspectives or assumptions on the basis of the engagement with the artistic or scientific counterpart. Situations like these point to what is needed in such collaborations, in addition to enthusiasm, imagination, dedication to a subject matter, and some ideas: the willingness and freedom to invest time and resources and the ability to be unafraid of being misunderstood or of not having all of the answers.

When working together, such frictions can become challenges that can be overcome and can provide rich potential to either learn or to push boundaries. Embracing frictions with a positive attitude, curiosity of the collaborating partner's ideas, and respectful conversation help to engage in understanding the reasons for the friction. This leads to learnings, adds a better understanding of other people's or disciplines' perspectives, and thus can also leverage the joint project. In so doing, friction is turned into something that I like to call *friction gains*. Such friction gains offer plenty of opportunities to learn and take advantage of and they introduce opportunities for creativity and increase the likelihood that innovative approaches or ideas will be generated. Understanding friction gains also implies looking at what happens along the way during such a collaboration, what the intense conversations are, what is needed to get to know and to understand each other, and to make the effort to make space for something new to emerge. Friction also certainly implies that there is the potential for challenges that need to be overcome, misunderstandings that lead to disruption, or additional efforts that need to be made; however, investing time and the energy in dealing with friction, using it, and learning from it provides rich and fruitful opportunities. Thus, it is possible to encounter friction and work with it in a constructive way.

## The actor and the process

In order to grasp this idea more easily it is helpful to see the art and science collaboration as a *process* that unfolds between individuals from different backgrounds, thereby seeing these individuals as *actors* who can learn from, and are subject to, social dynamics and who are embedded in cultural environments. For example, engaging with art and science addresses different skills needed for professionals in any of these aforementioned domains (Root-Bernstein et al., 2012) and, thus, helps these practitioners to train these skills in diverse settings or even to acquire new skills. Moreover, misunderstandings (Hauser, 2021) in the process between artists and scientists can provide valuable lessons. For example, artists and scientists need to elaborate on what they mean and this means in turn that they need to both talk their arguments through and present their perspectives in order to better understand each other and to understand where possible friction in their conversation might emerge. Moreover, different disciplinary jargons, which they use in their disciplinary work, can give rise to problems in communication across disciplines. Lastly, ideas that the artist discusses might excite the scientist, but possibly due to a misunderstanding or in terms of an aspect that the artist did not put at the forefront of their idea. The reason for this might be found in the language they are used to using, or in the professional cultural context that they are referring to – the scientific context proposes an altogether different framework than the artistic one. In such cases, when these misunderstandings are openly addressed as friction in their communication, they become valuable sources of insights. Both collaborating partners need to be aware of such friction and must engage to avoid this potential. In cases in which such misunderstandings are dismissed as noise, the situation can become frustrating for both parties: opportunities are missed and lessons delayed – or occur only for those who reflect on the misunderstanding.

Stories of friction in art and science collaboration can also include new lessons through changing ways of work processes that help individuals to learn and to reflect, and many more. Such a collaborative process can be intense, irritating, unexpected as artists and scientists often challenge each other in a different way than project partners from the same field or discipline might – or even could. Nevertheless, the frictions, that can lead to discussions, to explorations of new media, new experiments, new perspectives, or even adding unplanned work to the project partners, are more than just 'noise' – as frictions can be the root of noise – , but they also heighten the probability to distill new insights, lessons, and to explore the potentials that open up after boundaries have been pushed.

In that sense, it is possible to identify such friction gains by drawing from the comprehensive knowledge and theories found in fields as diverse as psychology, social psychology, sociology, pedagogy, social network theory, and cultural studies by looking at the actors and at their processes. For example, communication theories offer a lot of insights into why engaging art and science collaboration, and overcoming issues in communication, can be impactful (Schnugg, 2019). Taking insights further, it is possible to employ strategies that are also used in organization studies and to use these insights to make strong arguments for why organizations or funders might engage in this process (Schnugg & Song, 2020). A broader body of work is emerging that elaborates on this approach, adding more theoretical insights. For example, the potential knowledge production in art and science collaborations can be linked to learning theories (Kuchner, 2022) that elaborate upon the psychological processes of a challenging interaction that demands that project partners think in new ways and engage with new work processes and skills. Qualitative case studies aim to demonstrate how the interaction of artists and scientists push the boundaries of scientific disciplines, help to envision new scientific approaches, and establish mission-driven relationships with stakeholders (Jung et al., 2022). Other approaches aim at substantiating insights from theories for questionnaires, in order to evaluate art and science collaboration programs along the lines of potential impact on individuals, participants, and on the audience (Lau et al., 2022). These endeavors attempt to show the value for all participants and contribute to an environment in which artists and scientists can collaborate on a level playing field. In the remainder of this chapter, I will use a selection of social, psychological, organizational, and cultural theories that have previously been used to describe the impact of art and science collaborations to illuminate some valuable aspects of the processes of the four artistic residencies presented in this book.

I was curious to see how the four artists-in-residence selected would be able to dive into such an intense collaboration with their hosting scientific partners in a time at which COVID-19 restrictions challenged the process, e.g., by complicating travel and by limiting in-person meetings as well as access to laboratories for external partners. There is much to say about each of them, but we will have a look at their processes by singling out a few prominent aspects of their work in the following section.

As a composer with an additional background as computer programmer, Eduardo Reck Miranda's work was the perfect fit to engage with the SinFonia project at Prof. Pablo Iván Nikel's laboratory. The artwork that the artist realized, as well as the way in which he and the scientific team at the lab reflected on the process, shows that the high expectations that the matchmakers had were surely met. In his contribution about the residency, Eduardo Reck Miranda elaborates upon his creative process during the art and science collaboration along the lines of Nietzsche's idea of the dichotomy between the Apollonian and Dionysian that is found within the artist. In this concept, 'Apollonian' can be understood as the rational and structured approach, whereas 'Dionysian' stands for the irrational, passionate, and intuition-led approach. Eduardo Reck Miranda not only shows his personal battle between the inner need to organize versus the need to go wild, imagine, or explore along aesthetic[1] preferences, but he also elaborates on the challenges encountered during the process. Art and science collaborations are often advertised as being a cradle of creativity, both for the artists and for the scientists involved. Of course, an artist might be associated more with the Dionysian aspect by some people, whereas the scientist might be ascribed more Apollonian traits. In fact, both sides meet in each profession in order to lead to creative processes, even though the Dionysian and the Apollonian side might manifest differently in artists and in scientists. When they meet along the lines of a shared interest, such a collaborative process can challenge and truly inspire both, given time and willingness to engage with recurring open questions, irritations, and frictions. Leaving philosophy behind, looking at more recent psychological, social, or organizational theories of creativity, such as those by Teresa Amabile (1996) or by Richard Woodman et al. (1993), it is easy to demonstrate that such a process is charged with numerous triggers to heighten creativity, e.g., by giving the actors situations, new connections, questions, skills, or resources at hand to act and to think differently.

[1] "Aesthetic" here refers to the "judgment of taste", as for example elaborated by Immanuel Kant in his *Critique of Judgement*, which is not limited to visual impressions, but can relate to any art form or medium and can, thus, also be applied to sound. In order to better understand "aesthetics" that refers to diverse sensory stimuli – not only the visual – we might examine the approach based on the work of German philosopher Alexander Baumgarten, which draws upon the human senses and is applied to various art forms, including e.g., visual arts, performative arts, and poetry.

How the experience with the artist pushes creativity and diversity in the laboratory is also nicely expressed throughout the chapter by the scientists who collaborated with Eduardo Reck Miranda. This kind of open and reflective engagement helps, on a personal level, to gain new insights and to broaden one's horizons, which is something that the scientists state. This can have a lasting impact on the ways in which they approach their work in the future, or insights that might be influential in shaping future projects – even in case no specific ideas they discussed with the artist are planned to be taken any further.

Visual artist Isabelle Andriessen, whose artistic practice revolves around the creation of 'performative' sculptures, was invited to work in Prof. Lee Cronin's lab as part of the Madonna project. Her application stood out due to her artistic practice of having worked with inorganic materials, integrating them in sculptures and installations that seemingly come to life. The aesthetics of her work are driven by chemical processes as well as by a delicate balance of (apparently) non-living materials that expose processes that evoke lifelike impressions. Her work taps into chemistry while proposing developments without human intervention, which is why her work seems to have been fated to benefit from the experience at the Cronin Lab. In contrast to these expectations, Isabelle Andriessen was able to go further in her artistic work than simply integrating the knowledge provided in the laboratory into her artistic production. A delayed, short residency amidst lockdowns and video meetings neither provided the time or opportunity to dive deep into the nitty-gritty details of the scientific work during ongoing discussions with the scientists on-site, nor did it leave much space for hands-on work in the laboratory. Nevertheless, the deep dive into the subject matter in the time leading up to the residency, and the residency experience on-site thereafter, provided her with the opportunity to juxtapose the scientific knowledge researched in the lab and the media that the artist employed in her artistic installations. Starting with Prof. Lee Cronin's vision of chemistry computers and robots becoming the chemists of the future, Isabelle Andriessen developed a future vision of such a space: What does it look like? How does it feel? Who is operating it and how? This visual thought experiment is visually pleasing, but at the same time it enters into a challenging discussion with the scientist's vision. Engaging in this discussion, embracing the friction and potential for reflection, can reveal new insights that help to connect to stakeholders, audiences, and cultural values that can improve scientific and philosophical arguments around the ideas pursued by the scientists.

In both art and science processes it is not only theoretical insights, but also on-site experiences that can help the actors to step away from their traditional path and structures in order to see their own work – and their collaborative partners' work – from a truly different perspective.[2] Using an aesthetic and experiential approach supports such a learning process and this makes the collaboration of art with science especially valuable.[3] This helps to leverage existing practices onto a new path or to gain a meta understanding that helps us to connect to broader contexts. Even the medium chosen by the artist speaks to the necessity to abandon disciplinary hang-ups and, in this case, the artist employed film to tell a story, thereby stretching the boundaries of her established work. It will be interesting to see how reflections and insights from this process will become visible in Isabelle Andriessen's future work and how it might provide a challenging point of discussion for scientists.

Artist and filmmaker Karel Doing teamed up with Prof. Julian Ma's lab to explore their work within the Newcotiana project. Arriving at the laboratory, the artist had already developed a technique to work with plants in photography. Working in the laboratory, he was meandering between exploring his artistic practice among the plants with which the scientists were working, the scientists' tools, apparatuses, and physical environments including gestures, and the social and cultural environment in which the scientists operated. Karel Doing's process revolved around ideas of social and cultural constructs of understanding what we see: plants, scientific data, gestures, symbols, and materials. Such reflections are also necessary within scientific settings as they create an awareness of human agency and of the scientific process's human dimension. Although it has been a long time since Science and Technology Studies and philosophers of science have been able to create an awareness of the social embeddedness of scientific work,[4] mirroring

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[2] Much of the arguments for STEAM in education draw upon such insights, often going back to specific studies and to the seminal writings by Dewey (1934), Cassirer (1944), and Berger (1972).

[3] This has also been shown explicitly in the case of cosmologist Marcos Pellejero-Ibanez, who found a different perspective on his data through engaging with music and drawing parallels between sound, the physics of sound, his data and his own sensemaking of the information, see Schnugg (2019).

[4] Seminal works following Thomas Kuhn's *The Structure of Scientific Revolution*, but also prominently represented in the work of Bruno Latour and Donna Haraway.

practices and the reflection on cultural and social integration opens up scientists' minds within their everyday practice. Additionally, the scientific work – its content, object of research, or symbols used, traditions drawn from – can be reflected upon through artistic approaches. For example, artists often aim to contextualize their work, as well as the subject with which they work, within historical trajectories, social assumptions (is the tobacco plant the root of evil tobacco, or a generous plant that might be the source of remedies?), and mental constructs that education and living in a society entail. Just as Karel Doing concludes his chapter with the question of 'does everything have to be *either-or*, or can we find an *and-and* mentality including awareness of contexts and measure?', an awareness of these issues and of these questions is needed to reflect upon scientific processes and outcomes.

Visual artist and medical doctor Lara Tabet was invited to work in Prof. Víctor de Lorenzo's lab within the Madonna project. Looking at her process in the lab demonstrates how this temporary connection between a scientific group and an artist can work out as a liminal space. Liminality is a concept that has been developed in anthropology by Arnold van Gennep ([1909]1960) and Victor Turner (1966) who coined the term and elaborated upon it by linking it to their observations while working in the field with indigenous communities. It is a process that is linked to finding oneself at a threshold in a phase at which structures and previous knowledge become fluid before a change can happen. This can involve a change of status, such as the transition from childhood to manhood in indigenous communities, but it can also be understood as a time of transition at which a person starts a new position, or is allowed to realize a project in an organization that is not linked to the usual structures and demands, much like when a scientist is allowed to spend some time exploring new ideas while working with an artist instead of focusing on the next scientific journal publication. Artist-in-residence projects have been shown to support such liminal spaces for scientists or for the host institution's other collaborating partners (Schnugg, 2018). Lara Tabet's process is a wonderful example that provides insights into the liminal space that is also created for the artist-in-residence. As an artist, she has been working with a variety of visual media, developing a strong aesthetic in her work. Prior to the residency, she was engaged in exploring certain philosophical theories. She put all of this together in a proposal that was selected for the residency. When she arrived at the lab, these structures and ideas became fluid because she learned more about the processes, the science, and about the project's specificities and the laboratory. Thus, her thoughts evolved and took some turns so that two new strong artistic outcomes could emerge.

Conversely, Prof. Víctor de Lorenzo reflects on the process with the artist-in-residence by elaborating on the new perspectives and provocative questions that arose in the discussion with the artist. These discussions, and the artistic outcomes envisioned, inspired new experiments in the laboratory, e.g., new ways of dealing with their own materials and thought experiments around their scientific work that included human, cultural, and environmental contexts; this confronted the scientists with questions that they had not been confronted with previously. Some of these questions could also constitute interesting scientific projects and might, perhaps, even have paved the way for future projects that have been planted.

### The outcome and its relevance

Engaging in a process traditionally implies some sort of outcome. In project-oriented work, both art and science often operate on a project-by-project basis and writing funding applications also implies envisioning an outcome. The collaboration between artists and scientists can, thus, yield artistic outcomes, hybrid art-science outcomes, and scientific outcomes. Some questions about such outcomes, at the fringes of disciplines, arise therefore: Can there be outcomes that have a valuable impact within the respective discipline? Is the outcome interesting? Is anyone interested in the outcome?

Outcomes in art and science collaboration processes can originate from unforeseen frictions along the way, they can be planned before the start of the collaboration – such as public engagement or the goal of developing the envisioned artwork – , or they can manifest after the collaboration has ended. Lessons and friction gains are not usually considered as outcomes,[5] even though they are meaningful and contain valuable results from the collaboration process. They are rather considered as impact. Nevertheless, friction gains that are harnessed throughout the collaboration process inform the envisioned outcomes and elevate them to becoming stronger works: more innovative, more insightful outcomes are generated with greater depth. Artists, scientists, and curators regularly state that outcomes are

[5] There are only a few art and science programs that focus on the lessons and friction gains instead of artworks, scientific or other innovative outcomes. The Mission Art-Space Exchange Artistic Research Residency at the European Space Agency ESTEC is a noteworthy exception.

richest in art and science projects that also allow for additional exploration and for unexpected outcomes (in contrast to the realization of previously planned outcomes), as argued in Jung et al. (2022), Wilson, Hawkins, and Sims (2015), and Schnugg (2019). Artworks, scientific insights, new research questions, and hybrid art-science manifestations of the collaborative process are all typically understood as outcomes. The stronger these works are, the more relevance they will have in their respective fields of art and science; they will also be more impactful in the conversation between the fields and for engaging with audiences. In the remainder of this chapter, we will briefly look back at the four cases and will reflect on some of their outcomes.

Reflecting on the artwork, and upon the possibly related public engagement, scientists and artists often team up because these are issues that are dear to them and are central to the work that they want to critically discuss with the public. Víctor de Lorenzo and his team discuss how they want to address certain global challenges with their work, and Lara Tabet also aims at a critical and open reflection about the implications of synthetic biologists' work. Through open discussion, and sometimes colliding views between artists and scientists, an awareness among them in their collaboration process is created, and this new awareness and their intentions can feed into processes that engage with public audiences. By tapping into art in particular, it is possible to go beyond transmitting content to an audience, but to also connect this content to the cultural, social, and even political dimensions in which it needs to be discussed. It is important to note that this kind of artistic work is not considered as just another kind of science communication, but can involve engaging with the artwork and learning about it which helps to connect to the science with which the artwork deals. Aspects of working with art, such as storytelling, experiences with the artwork, aesthetics, contextualization of the artwork within cultural, societal, and political issues, tapping into multiple ways of knowing, and connecting to the audience in a personal manner all support this process.

Karel Doing's artistic work plays on symbols, gestures, and historical contexts that are also important in terms of how societies might interpret both science and scientific endeavors. Scientists engaging in such reflections can become aware of routines, habits, and the additional cultural or societal meaning of their processes. Isabelle Andriessen's work goes beyond cultural and social contextualization, but thinks scientific ideas consequently to the end, thereby mirroring this back to herself in the artworld, science, technology, and society. Deeply researched work, such as this, is also relevant in the artistic discourse on knowledge production, societal and cultural values, or political questions. Such work is gaining growing interest in the contemporary art discourse, especially in the growing discussion about plurality of knowledge, around more-than-human connections (Haraway, 2016), and in the wake of global challenges.

Though art-science work often has this inherent drive of critical discussion, relevant artworks in the context of the contemporary art world are becoming more frequent – and art and science work are becoming recognized in terms of their aesthetic and thematic contribution, as even the most recent Biennale di Venezia 2022, curated by Cecilia Alemani and national participations, show. Artists working in art and science are no longer just working at the fringes of the artworld, but are increasingly becoming part of new developments in their field. Thus, art and science works are also making noise within the art domain, thereby adding to critical reflections about what art is in this ever-changing world that is confronted with global challenges and with rapid developments in both science and technology.

As frictions often come from the meeting of different perspectives, different background knowledge, and different languages, the interaction between art and science professionals from different backgrounds is also characterized by translation: translation processes between the arts and the science, translation processes between experts (artist, scientist) and non-experts (non-artist, non-scientist), but also a translation process of knowledge to different forms of expression: music, (micro-)performance, visuals, and sculptures. These translations play a role within the process – and contribute to friction gains – and they become experienceable for an audience in the outcome through aesthetic expression. The artwork – the outcome – of Eduardo Reck Miranda translated the work of Dr. Pablo Iván Nikel and his group into music, thereby creating a translation of enzymes into sound, something the scientists have not experienced before. As they say, they are used to seeing them as structures and models – which are also aesthetic translations from the actual enzyme into something that can depict it visually or in code – , but they do not usually hear them. Perhaps this new kind of translation and experience will initiate another process between the artist and the scientists or it might bring new insights and future outcomes individually to the fore, on condition that they follow this direction.

# BIBLIOGRAPHY


01. Amabile, T.M. (1996). *Creativity in Context.* Boulder, CO: Westview Press.
02. Berger, J. (1972). *Ways of Seeing.* London: Penguin.
03. Cassirer, E. (1944). *An Essay on Man.* Boston: Yale University Press.
04. Dewey, J. (1934). *Art as Experience.* Boston: Tarcher Perigree.
05. Haraway, D. (2016). *Staying with the Trouble. Making Kin in the Chthulucene.* Durham and London: Duke University Press.
06. Hauser, J. (2021). Fruitful misunderstandings: Artistic research in art/science within the epistemological turn. In: *Sztuka I Dokumentacja / Art & Documentation*, Vol. 24.
07. Jung, J. et al. (2022). “Doubling Down on Wicked Problems: Ocean ArtScience Collaborations for a Sustainable Future” *Frontiers in Marine Science,* https://doi.org/10.3389/fmars.2022.873990.
08. Kuchner, U. (2022). The value of ArtScience: improving the balance in collaboration in practices between artists and scientists can impact knowledge production. *Writing Visual Culture*, Vol. 10.
09. Lau, C., Barriault, C., & Krolik, J. (2022). “Evaluating the Impact of a Comprehensive Canadian Science-Art Residency Program on the Participating Scientist, Artist and the Public” *Frontiers in Education*, https://doi.org/10.3389/feduc.2021.690489.
10. Root-Bernstein, R. et al. (2012). “Arts, Crafts, and STEM Innovation: A Network Approach to Understanding the Creative Knowledge Economy” In: Rush (Ed) *Creative Communities, National Endowment for the Arts and The Brookings Institution*, pp. 97-117.
11. Schnugg, C. (2018). Setting the Stage for Something New *Zeitschrift für Kulturmanagement*, Vol. 4, http://dx.doi.org/10.14361/zkmm-2018-0204.
12. Schnugg, C. (2019). *Creating ArtScience Collaborations*, Springer, Cham, https://doi.org/10.1007/978-3-030-04549-4.
13. Schnugg, C., & Song, B. (2020). An Organizational Perspective on ArtScience Collaboration: Opportunities and Challenges of Platforms to Collaborate with Artists. *MDPI 6*(6), https://doi.org/10.3390/joitmc6010006.
14. Turner, V. (1966). *The ritual process: Structure and anti-structure.* Ithaca, NY: Cornell University Press.
15. Van Gennep, A. (1909). *Les rites de passage* (Rites of passage, 1960). London: Routledge and Kegan Paul.
16. Wilson, B. Hawkins, B., & Sims, S. 2015, Art, Science and Communities of Practice. *Leonardo 48*(2): 152-157, https://doi.org/10.1162/LEON_a_00972.
17. Woodman, R.W., Sawyer, J.E. and Griffin, R.W. (1993). Toward a theory of organizational creativity. *Academy of Management Review 18*(2): 293–321.

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