My Collaboration with Bacteria for Paper Production

Mindaugas Gapševičius

15 August 2019

I love the fact that human genomes can be found in only about 10 percent of all the cells that occupy the mundane space I call my body; the other 90 percent of the cells are filled with the genomes of bacteria, fungi, protists, and such, some of which play in a symphony necessary to my being alive at all, and some of which are hitching a ride and doing the rest of me, of us, no harm.
— Donna Haraway

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Introduction

This paper invites to experience symbiotic relationships while experimenting with the tools provided. Symbiotic relationships are outlined with references to artistic projects and scientific research. It refers mainly to three different kinds of research: a theory of the origin of eukaryotic cells proposed by Lynn Margulis, formerly Lynn Sagan (Sagan, 1966), the Human Microbiome Project carried out by the National Institutes of Health in the United States (NIH, 2012), and a manifesto-like proposal of interspecies dependencies by Donna Haraway (2008).

In addition, the paper provides a step-by-step manual for the use of the toolkit (Fig. No. 5): In the first case we will grow SCOBY, and in the second we will isolate *Acetobacter* bacteria from grown SCOBY in order to further cultivate colonies of single species. Altogether symbiotic relationships are experienced through experimentation with living microorganisms and non-living components, which enable the experimentation.

Related Artworks

Symbiotic relationships between organisms are questioned while discussing interaction among members of the same species, envisioning the influence of one species over the other, and proposing evolutionary contexts. Introduced below are four projects covering the discourse related to symbiotic relationships.

Nurit Bar-Shai, *Objectivity [tentative]: Soundscapes*[1]

This artwork (2012-2013) contains a number of petri dishes hung on the wall, which together shape horizontal and vertical lines. The petri dishes are inoculated with dyed bacteria *(Paenibacilus vortex)* that have been grown on an agar medium with necessary nutrients (Fig. No. 1). In his book *Bio Design* (2012), Willem Myers described the artwork in the following:

> *In visualizing biological systems of self-organization, it is possible to detect surprising complexity and to achieve dramatically varied results with only slight alterations in the initial environment. (…) These pieces examine the decision making of living, performative objects that 'grow images' as a sculptural form. (…) These microorganisms possess advanced social motility, employing cell-to-cell signaling to prompt activities such as attraction and repulsion under different environmental conditions. (…) Once the bacteria have grown into patterns, prompted by the dispersal of nutrients, they are made visible with dye that also halts their growth. (Myers, 2012)*

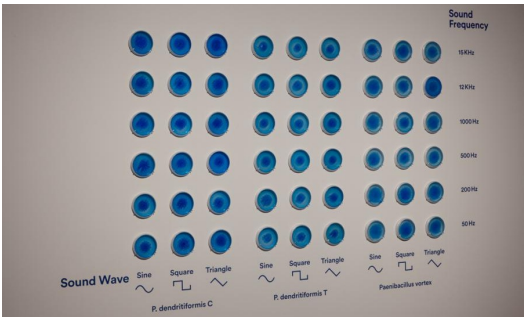


Fig. No. 1. Nurit Bar-Shai, *Objectivity [tentative]: Soundscapes* (2012–2013), in *Exo-Evolution*, ZKM, 2015 / © Photo: Jonas Zilius ZKM | *Zentrum für Kunst und Medientechnologie*

The work brings up the context of self-organization and collaboration between bacteria in *Paenibacilus vortex* bacterial colonies. The discourse introduced could be expanded to networks of bacteria sending signals from cell to cell while searching for food. The artwork also introduces the bacterial species as "intelligent" through its ability to draw fractal-like patterns.

*1 http://www.nuritbarshai.com/objectivity/

Tarsh Bates, *The Unsettling Eros of Contact Zones*[2]

In the exhibition description (2015), the artist wrote:

> *An exhibition exploring what it means to be human when we recognise our bodies as multi-species ecologies, with a particular focus on the relationships between Homo sapiens and Candida albicans. I used scientific and artistic methodologies to explore physical, emotional, cultural and political relationships between humans and Candida. Works comprised sculptural, photographic and filmic works, dead and living organisms, and were developed during my PhD research at SymbioticA and the University of Western Australia.*[3]

The installation (Fig. No. 2) uses a variety of materials, including organic artisanal white bread leavened with *Candida albicans* and *Saccharomyces cerevisiae* yeast strains, brie, blue cheese, and hummus. During the event, the public was invited to taste bread baked with traditional yeast and yeast that normally lives in human bodies.

Fig. No. 2. Tarsh Bates' exhibition *The Unsettling Eros of Contact Zones* at the Gallery Central Shopfront, 2015. Photo: Megan Schlipalius.

Besides the discourse on symbiotic relationships between yeast and humans, Bates also raises ethical questions regarding the consumption of organisms, especially those living in close relationships with humans. It also questions borders between organisms of similar bacterial strains: If we consume bread without questioning the presence of the *Saccharomyces cerevisiae* strain, why would we then question eating bread with *Candida albicans*, another similar bacterial strain that lives in our bodies?

*2 https://tarshbates.com/portfolio/t-he-unsettling-eros-of-contact-zones-2015/
*3 https://tarshbates.com/portfolio/the-unsettling-eros-of-contact-zones-and-other-stories-2015/

Christina Agapakis and Sissel Tolaas, *Selfmade*[4]

The *Selfmade* project was part of a larger exhibition in Dublin Science Gallery in 2013, curated by artist and designer Alexandra Daisy Ginsberg, Anthony Dunne (Royal College of Art), Paul Freemont (Imperial College), Cathal Garvey (bio-hacker), and Michael John Gorman (Science Gallery).

Fig. No. 3. Cheese made from human toe bacteria. Photo: http://cultofweird.com

Scientist Christina Agapakis (US) and scent expert Sissel Tolaas (NO) collected bacteria from noses, tears, and other parts of different bodies in order to produce cheese (Fig. No. 3). The artists described their project as follows:

> *Selfmade is a series of "microbial sketches," portraits reflecting an individual's microbial landscape in a unique cheese. Each cheese is crafted from starter cultures sampled from the skin of a different person. Isolated microbial strains were identified and characterised using microbiological techniques and 16S ribosomal RNA sequencing. Like the human body, each cheese has a unique set of microbes that metabolically shape a unique odour. Cheese odours were sampled and characterised using headspnace gas chromatography-mass spectrometry analysis, a technique used to identify and/or quantifyn volatile organic compounds present in a sample.*[5]

The idea behind the project goes back through hundreds and thousands years of history, when microorganisms from human bodies accidentally appeared in milk and milk products and fermented and hardened them into what we now know as cheese. Although symbiotic relationships between microorganisms are directly present in cheese production, cheese would not have become cheese without the microorganisms living on and inside the human body.

*4 http://agapakis.com/cheese.html
*5 https://dublin.sciencegallery.com/growyourown/selfmade

François-Joseph Lapointe, *1000 Handshakes*[6]

1000 Handshakes was performed for the first time at the Panum Institute, University of Copenhagen, in 2014. Later the same year, it was repeated at the Medical Museion in Copenhagen, as well as during the Transmediale festival for media art and digital culture in Berlin (2016). For his performance, biologist and bioartist François-Joseph Lapointe from Montreal shook hands with 1000 people (Fig. No. 4). Being a scientist, Lapointe approached his work from a scientific research perspective as well, collecting bacterial samples from his hands and analyzing them in the laboratory. The result – visualized networks of bacterial species – were presented at the Art Laboratory Berlin gallery in 2016 within a larger series of exhibitions entitled *Non Human Subjectivities*.

Fig. No. 4. *1000 Handshakes* at the Transmediale Festival in Berlin, 2016. Photo: Art Laboratory Berlin, http://artlaboratory-berlin.blogspot.de/2016/02/francois-joseph-lapointe-1000_4.html

According to Art Laboratory Berlin, "The performance raises awareness through physical and social engagement, through acts of participation and exchange on social, individual and microbial levels. The handshake, a basic and ancient act of networking forms the beginning of a social, scientific and artistic collaboration between the performer and the public." It also extends the discourse on relationships between humans and bacteria into the symbiotic social network, adding an additional discourse of shared human and non-human networks.

*6 http://www.museion.ku.dk/whats-on/exhibitions/30119-2/30129/1000-handshakes/

Concept

The project provides tools that invite the user to explore their own relationships with organisms and to grasp invisible creatures surrounded by the outer world. By using SCOBY as a metaphor for the complex organization of microorganisms, the experimentation reflects on the role of a single organism in relation to its environment.

How to best understand the complex behavior between non-living things and living organisms? What is their interaction and how does it become symbiosis? The experienced symbiosis aims at further discussions of evolution, the diversity of organisms, and, finally, the interaction between chemical compounds of living organisms and non-living tissues.

Symbiotic Relationships

The idea introduced in this paper and the toolkit is wrapped around the interaction between different types of organisms. It also introduces interactions between chemical and organic elements, which, while interacting, trigger the appearance of newly shaped tangible or intangible elements and, on a global scale, trigger evolutionary processes. These interactions could be defined as symbiotic relationships, or, as Donna Haraway puts it, “companion species.”

Proposal of Interspecies Dependencies by Donna Haraway

While introducing the companion species idea, Haraway has talked about her sheepdog, Ms. Cayenne Pepper, with whom Haraway has shared interactions, exchanging, for example, saliva and, along with it, genes and bacteria, making them part of herself. In so doing, Haraway asked, “who ‘we’ will become when species meet” and proposed the uniqueness of an organism as being shaped via the processes of various interactions with different species (Haraway, 2008). The discourse here goes far beyond a traditional, let’s say, Cartesian *(Cogito ergo sum)* or Nietzschean (*the Übermensch*) understanding of the human, wherein the former defines human existence by the ability to think and the latter defines the human as striving to overcome their own limitations. In Haraway’s case, the

human is defined by collaboration with other species. This idea has been developed by Haraway while referring to evolutionary theorist Lynn Margulis. Meanwhile, research on human microbiota has been carried out by the National Institutes of Health.

Theory of the Origin of Eukaryotic Cells

As an evolutionary theorist, Lynn Margulis criticized the traditionally accepted theory of evolution proposed by Charles Darwin; she introduced evolution as merely a collaborative interaction rather than a struggle for existence. If the struggle for existence in Darwin's theory led to natural selection and survival of the fittest (Darwin, 1859), Margulis introduced a theory of symbiotic organisms wherein, through interaction and collaboration, prokaryotic organisms evolved into more complex eukaryotic cells (Sagan, 1966). In her article "On the Origin of Mitosing Cells," the theory is introduced through the interaction of three ancient organelles: mitochondria, photosynthetic plastids, and flagella, which, over the course of changing weather conditions during Earth's history, were impelled to mutate into one organism. This process was possible due to vapor and the escape of free hydrogen into the upper atmosphere, which led to the production of molecular oxygen. The increasing amount of oxygen, in turn, was consumed by other organisms that had to survive in the changing conditions: An aerobic prokaryotic mitochondrion was ingested into the cytoplasm of a heterotrophic anaerobe, while symbiotic cilium attached to other bacteria and formed a flagellum. Further evolution resulted in eukaryotic blue-green algae:

During the course of the evolution of mitosis, photosynthetic plastids (themselves derived from prokaryotes) were symbiotically acquired by some of these protozoans to form the eukaryotic algae and the green plants. (Margulis, 1966: 225)

The idea of evolutionary change via interacting organisms suggests that we humans are not humans because we "think," but because we interact with other organisms and we evolve with other organisms. Therefore, the discourse opens up awareness of whom we interact with and how we interact. This awareness brings us closer to acknowledging symbiotic processes within and around other organisms.

Human Microbiome Project

The National Institutes of Health carried out a project analyzing and sequencing the variety of DNA in the human body, coming to the conclusion that the ratio of human cells to other cells within the body is one to ten. The cells belonging to humans have one DNA strand, and those of other organisms have the other. Those other organisms carrying different DNA are various fungi, bacteria, and protists that live on the skin, in the guts, or in the nose:

Microbes inhabit just about every part of the human body, living on the skin, in the gut, and up the nose. Sometimes they cause sickness, but most of the time, microorganisms live in harmony with their human hosts, providing vital functions essential for human survival. (NIH, 2012)

To define the human microbiome, researchers at the National Institutes of Health analyzed 242 people by taking samples from different parts of the body and analyzing them with DNA sequencing machines, instead of by growing microorganisms in a medium under laboratory conditions. This way they ended up with more accurate results. It follows that the more than 10,000 other microbial species occupying the human ecosystem must have a function that is more than just to lurk around the body and consume energy provided by digested food. Microorganisms break down proteins, lipids, and carbohydrates, readying them to be absorbed by the human organism. They also produce vitamins and anti-inflammatories that regulate the immune system and keep the human body safe from diseases (NIH, 2012). In short, microorganisms have been collaborating with humans for survival for time immemorial over the course of evolution.

So, what is crucial to evolution is the interaction over time between organisms, including the smallest and the biggest: bacteria, fungi, protists, plants, and animals. Some of them produce oxygen and some consume it, some of them break down compounds and some absorb broken down chemical elements. Everything is in constant interaction and symbiotic relationship, including living organisms, chemical compounds, and inorganic elements.

SCOBY

To introduce symbiotic relationships between organisms, I use SCOBY. The culture is comprised of mixed strains of bacteria and yeast present during the fermentation process within a kombucha tea. The DNA sequencing analysis of the bacterial and fungal populations of five distinct SCOBY samples introduced in "Sequence-based Analysis of the Bacterial and Fungal Compositions of Multiple Kombucha (Tea Fungus) Samples" (Marsh et al., 2013) resulted in a number of *Acetobacter* and *Saccharomyces* species, or more specifically: *Gluconacetobacter* (in some papers, also referred to as *Komagataeibacter* or *Acetobacter*) was present in more than 85% of all samples, *Lactobacillus* was present in up to 30% of the samples analyzed, *Zygosaccharomyces* was present in more than 95% of the SCOBY samples, and *Acetobacter* was detected in less than 2% of samples. A great variety of other microbial bacteria and yeasts, including *Candida*, *Saccharomyces*, and *Saccharomycoides*, were also present (Marsh et al., 2013).

Fig. No. 5. Toolkit for introducing symbiotic relationships between organisms. Photo: Christian Döller.

Toolkit

The toolkit has been designed to enable the discussion of symbiotic relations between living organisms and non-living things. At the same time, its aim is to develop an awareness of interspecies dependency, including with the user of the kit. The toolkit includes jars with chemical elements and ingredients, along with a sample of SCOBY in kombucha tea. It also has a set of the tools necessary for isolating *Acetobacter* bacteria from SCOBY (Fig. No. 5).

Within the two experiments introduced, I show how to grow microorganisms. This project could be seen from the perspectives of discourses on symbiosis, learning purposes, and artistic practices (Gapševičius, 2019).

Experiment No 1: SCOBY and Kombucha Tea

This experiment introduces the growth of SCOBY, which, if dried out, could be used as bacterial paper (Fig. No. 6). The experiment could also be useful from the perspective of consumption because the growth of SCOBY produces a fermented tea, which could be imbibed as a beverage. If the fermentation process takes longer, the result could be used as a vinegar for different meals.

To prepare 50 ml of liquid to grow SCOBY and to also brew kombucha tea, we will use:

Equipment:
- An electric stove;
- A strainer;
- A sheet of baking paper;
- A piece of cloth;
- A jar;
- Scales.

Ingredients:
- A piece of the SCOBY within kombucha tea – 5 ml;
- Tap water – 50 ml;
- Green tea – one tea bag;
- Sugar – 2.5 g.

- Boil the water in order to kill unwanted microorganisms.
- Add a tea bag. Leave it in for at least 10 minutes to steep and throw it away afterwards.
- Add sugar and mix the solution thoroughly until the sugar dissolves.
- Allow the tea solution to cool to room temperature and add to it the sample of the SCOBY with kombucha tea. Place the jar in a safe place. It will take 2 to 3 days to see the start of the formation of the new SCOBY. After around 10 days, your SCOBY floating on top of the tea should reach 3 to 5 mm in thickness.

- Use a strainer to strain it from the unwanted bacterial pellicle. The brewed kombucha tea should be ready to drink.
- Put the grown SCOBY on the baking paper and let it dry for a couple of days until the pellicle is ready to be used as bacterial paper.

For further experimentation, use black tea, red-beet juice, or other natural ingredients. You may also want to experiment with growing the pellicle for different lengths of time, or in differently shaped containers (Gapševičius, 2019).

Fig. No. 6. Bacterial paper.
Photo: Mindaugas Gapševičius.

Experiment No 2: Preparation of Media for the Growth of *Acetobacter*

This experiment introduces the isolation of *Acetobacter* from the SCOBY culture. The experiment shows how to inoculate microbial species from one single colony, which could be interesting for further research and analysis of living organisms. The grown *Acetobacter* could be further used for the production of cellulose.
To prepare 50 ml of *Acetobacter* medium, we will use:

Equipment:	Ingredients:
- An electric stove;	- A sample of the SCOBY within kombucha tea;
- A knife;	- Glucose – 1 g;
- A marker;	- Peptone – 0.25 g;
- A jar;	- Yeast extract – 0.25 g;
- Agar plates;	- Disodium phosphate – 0.14 g;
- A pipette;	- Agar – 0.8 g;
- Scales.	- Citric acid – 0.08 g;
	- Distilled water – 50 ml.

- Mix the ingredients as outlined.
- Boil the mixture in order to sterilize it.
- Sterilize the agar plates provided.
- Pour the medium into each of them, and leave it all to stiffen.
- Cut a couple of square millimeters of SCOBY out of the culture provided.
- Put the pieces of SCOBY into the empty jar. You may add some kombucha tea as well.
- Add some distilled water to the jar.
- Shake the mixture for a couple of minutes so the microorganisms dissolve into the water.
- Pour a drop of the solution onto the first plate.
- Spread the solution with the paper clip.
- Prepare a 1:10 solution of dissolved microorganisms; use a pipet and the empty jar (Fig. No. 7).
- Pour one drop of the solution onto the second agar plate.
- Spread it with the sterile paper clip.
- Repeat the 1:10 dilution with the diluted solution and pour the third agar plate. Repeat this process with the forth and the fifth agar plates. This will insure that you identify the *Acetobacter* colony grown from one single bacterium. Leave the sixth plate unchanged.
- Label your agar plates with a permanent marker for your records.
- Flip the agar plates upside down and leave them at room temperature for the next 2 to 3 days.

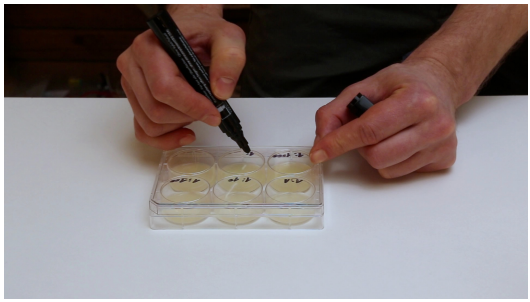


Fig. No. 7. Different solutions of dissolved microorganisms. Photo: Brigita Kasperaitė.

- After those 2 to 3 days, inspect your agar plates (Fig. No. 8).
- In our case, the first agar plate shows diverse colonies of bacteria that spread all around, and one colony of yeast that developed on the right side of the plate. The second plate has three colonies of *Acetobacter* in the middle of the plate. The third plate has only one colony on the right side. The fourth and fifth plates have no bacteria and no yeast, which means that the sample with kombucha had been diluted too much. So, the most successfully isolated bacteria are on the second and third agar plates. We will use the colony on the third plate for the new inoculation.
- Use the sterile paper clip to take the visible sample of the *Acetobacter* bacteria from one colony.
- Inoculate it into the sixth agar plate by carefully placing it onto the gel. If the experiment was successful, it should be clean.

For further experimentation, try isolating the *Lactobacillus* bacteria or *Candida* fungi found, for example, in saliva. Use medium appropriate for the microorganisms you want to isolate (Gapševičius, 2019).

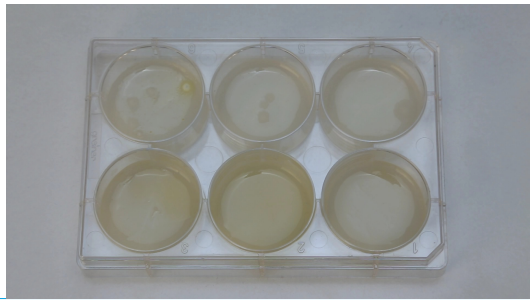
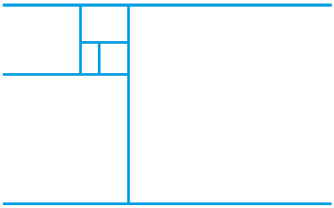


Fig. No. 8. Acetobacter growth after 2-3 days. Photo: Brigita Kasperaitė.

Conclusions and Further Discourses



Through the philosophical insights of Donna Haraway, an alternative approach to evolution by Lynn Margulis, the results of DNA sequencing of the human microbiome by NIH, the aesthetic outcomes of a number of artists, and practical step-by-step instructions for working with microorganisms, this project has introduced symbiotic relationships between living organisms and non-living things. Although the title proposes "collaboration" with bacteria for paper production, the goal of the project is to lead the reader towards the imagining of possible interactive settings – in this case, growing symbiotic SCOBY cultures and isolated *Acetobacter* bacteria strains. While learning is pursued through the use of the toolkit, the artistic nature of this project is comprised of the results of experimentation, which are documented in photos and time-lapse video clips.

Introducing symbiotic relationships through experimentation, the project opens up further discourses. One of these discourses is, for example, mutation, which would occur while experiencing the grown microorganisms. If put in broader terms – over the course of evolution, mutation has played an important role for organisms in becoming slightly different from their parents. While self-replicating, interacting with each other, and mutating according to changing environmental conditions, early prokaryotic organisms were able to evolve into what is now a variety of living species.

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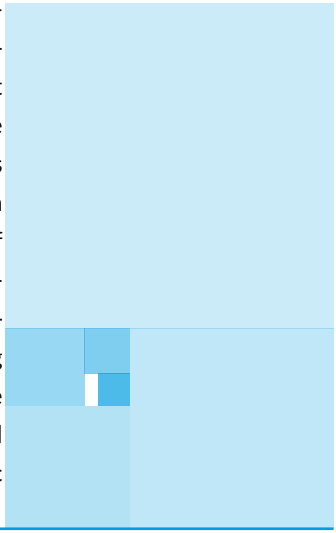
This project is part of the *Introduction to Posthuman Aesthetics* project, initiated in 2016. The discourse introduced in the paper and the toolkit invite the reader and toolkit user to experience symbiotic relationships between living organisms and non-living things. The paper is organized in four parts. The first part is a short compilation of related artistic projects, the second part introduces the concept of this project, the third part presents the idea of symbiotic relationships among organisms, and the last section introduces the toolkit, an artistic and educative set of tools and ingredients for experimenting with a symbiotic culture of bacteria and yeast (SCOBY).



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