Biohacking

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The Handbook of Peer Production

Chapter 16 – Biohacking

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1. Introduction

Over the past few years, a plethora of terms have emerged to describe scientific activities in the life sciences that happen outside traditional institutions: biohacking, garage biology, DIY biology, DIY genetics, DIY medicine, DIY science, and so on and so forth. These movements have attracted a growing number of enthusiasts, from young students to professional scientists, from artists to aspiring entrepreneurs, from people with no technological background to computer hackers.

The diversity of people interested in DIY science has also generated a large diversity of activities: extracting DNA for genetic testing, producing bioreactors, creating fermentation kits (i.e. for homebrewing), doing bio-art projects, developing biosensors (i.e. to detect the presence of contaminants in the environment or in food), giving lectures and organizing workshops, and fabricating cheaper alternatives to scientific equipment. The DIYbio movement has become an object of interest for journalists, for museums and, occasionally, for decision makers. The DIYbio movement can also be of interest for people who analyze peer production since similar dynamics can be observed (i.e. the emphasis put on flat hierarchies, openness and decentralization). However, while peer production has become the subject of a large body of academic literature – analyzing for instance practices in the fields of computer software and hardware – the field of biology is usually not examined in this literature.

In this chapter, I first provide an overview of the history, and the various practices of DIY biology. Thereafter I offer a few examples of DIY medicine. I then discuss and analyze some of the key issues of DIY biology: the openness of the movement (section 5), what the "yourself" in do-it-yourself stands for (section 6), and concerns with ethics and governance (section 7). The penultimate section of the chapter looks at the economic aspects and the valuations of DIY biology. In the conclusion, I will argue that further academic work could look into the geographies and fragilities/instabilities of DIY biology, and its relation with the public.

2. History

The history of DIY biology is both a recent and a long one. In terms of its recent history, 2008 is usually mentioned as being its year of birth. The first DIYbio meeting took place in a pub in Cambridge, Massachusetts, on the 1st of May of that year. Several months later, in February 2009, the Hackteria network was created, a network linking people interested in open source bio-art from countries such as the Czech Republic, Switzerland and several Asian countries. From 2009 onwards, stories such as those of Kay Aull, a student who managed to carry out a homemade test to detect hemochromatosis (a genetically transmitted disease that affects the metabolism of iron), became widely reported in the media. And in 2010, the *Biopunk Manifesto* was released by Meredith Patterson, one of the most visible members of the biohacking movement. But even before 2008/2009, terms such as “garage biology” and “DIY biology” began to circulate. In 2005, for instance, biologist Rob Carlson (2005: unpaged) predicted that “The advent of garage biology is at hand. Skills and technology are proliferating, and the synthesis and manipulation of genomes are no longer confined to ivory towers”. In 2006, biologist and computer scientist Attila Chsordash (2006, p. n.d.) wrote about “the coming world of personal biotech”, signifying that the “beautiful retro idea of tinkering with digital devices in a garage […] can be extended to biotech too”; he also used the term “bioDIY.”

Among the first laboratories dedicated to DIY biology, we can mention BiologiGaragen in Copenhagen (2010), Genspace in New York (2010), Biocurious in Santa Clara (2010) and La Paillasse in Paris (2011). At the time of writing (September

2020), the website diybio.org lists 109 groups across the world. Most of these groups are located in the Global North (40 in Europe, 42 in the US, 8 in Canada) with a smaller number in Asia (8) and in South America (6). Roughly half of these groups have created their own laboratories.

Despite this recent history, the genealogy of DIY biology is more complex, and needs to be traced back in connection to various other developments within – but also outside – of science. First, as the term biohacking suggests, there is a close connection between biohacking and hacking. The connection is not only semantic but also ethical and philosophical: ideals such as openness, access, sharing, and decentralization are key principles in both fields. There is also a spatial proximity between these areas of practice. Numerous activities and groups did start off within already existing hacker labs. For example, in 2011 several DIY biology projects were launched at the MadLab in Manchester (created in 2008 - see Bell, Fletcher, Greenhill, Griffiths, & McLean, 2014) and there are numerous accounts of people, such as Berlin resident Lisa Thalheim, who moved from computer hacking to biohacking (Charisius, Friebe, & Karberg, 2013). This does not mean that there was an easy co-habitation. At the Noisebridge hackerspace in San Francisco, for instance, computer hackers complained about smells and were allegedly disgusted by the wet lab work carried out by DIY biologists (Charisius et al., 2013, p. 53).

DIY biology is embedded within the larger peer production and open source movements that have developed since the 1990s. DIY biology is not the only field that has roots in the hacking and open source movements: open source agriculture (Chance & Meyer, 2017), open source ecology (Thomson & Jakubowski, 2012), and open source architecture (see Parvin, 2013) are other examples. The rise of DIY biology is also closely connected to the maker movement and the magazine MAKE which have provided a “hospitable” forum (Tocchetti, 2014, p.136). The maker movement, in turn, can be linked to the do-it-yourself tradition, that developed from the 1950s and 1960s onwards (including dedicated magazines, books, shops and TV shows). Some DIY biologists have also been involved in setting up the *Gathering for Open Science Hardware* in 2016 and, thereafter, the launch of the *Journal of Open Hardware* in 2017.

Apart from these links to hacking, making and open source, there is also a connection between DIY biology and synthetic biology. The vision promulgated by synthetic biology – that engineering principles can be applied to biology in order to create new substances or organisms – has been influential. Numerous founders of DIY biology laboratories have met at the international Genetically Engineered Machine (iGEM) competition for students in synthetic biology. Some of the key features of the iGEM competition – a mix between entrepreneurial spirit, fun, team-work, reflections on ethical and social issues, and a positive attitude towards science – can also be found in DIY biology laboratories. However, until 2013, DIY biology laboratories were excluded from the competition – issues of security, responsibility and governance were put forward as the reasons. It was not until 2014 that a “community labs” track was opened at the competition in order to welcome projects from community laboratories.

Finally, the rise of DIY biology can be placed within the longer history of the contribution of amateurs and citizens to science. Four examples can be mentioned here. A first example is what has been called popular epidemiology, “a process by which laypersons gather scientific data and other information, and direct and marshal the knowledge and resources of experts to understand the epidemiology of disease” (Brown, 1992). Second, AIDS treatment activists are also involved in the production and evaluation of biomedical knowledge (Epstein, 1995). In this case also, laypeople engaged in scientific practice and thus challenged the idea that only experts can engage in research practices. A third example is the French Association of Muscular Dystrophy (Callon, Lascoumes, & Barthe, 2001), an association mainly composed of patients and their families that is sometimes actively involved in scientific research and collaborates with professionals. And, fourth, in natural history there is a long tradition of amateurs doing fieldwork and producing knowledge (Alberti, 2001). These are just a few sites of what we could call the spaces of amateur science. The spaces of amateur science are, on the one hand, related to specific disciplinary fields: natural history (including botany, zoology, entomology, ornithology), astronomy, epidemiology, etc. On the other hand, there are specific physical locations in which we can observe amateurs producing and sharing knowledge: the field (to make observations, see Kuklick & Kohler, 1996), the museum (to work with specimens, see Ellis & Waterton, 2005; Star & Griesemer, 1989), the pub or the coffee house (as a meeting place for learned societies, see Secord, 1994), or even the home.

Several authors have reflected about the links between DIY biology and amateurs in the natural sciences. Roosth (2010, p. 119) believes that the difference lies in “observation” as opposed to “making new things, building, tinkering, modifying.” Historian of science Curry (2014), on the other hand, stresses historical continuity while arguing that both “share characteristics” and that “parallels can be found”.

3. Practices and Identities

Within DIY biology, very diverse activities and projects are carried out, concerned with agriculture, the environment, health, scientific equipment and protocols, food, education, museums, art, etc. The projects that have been presented at the iGEM competition (see table 1) provide a sense of this heterogeneity.

Year	Name of the team	Name of the project	Description of the project
14	BUGSS Baltimore	Polymerase to the people!	Development of a new Biobrick for the Pfu polymerase by amplifying and cloning the gene of the polymerase, and by developing a kit for purification in order to reduce costs
	The Tech Museum	e.Mosaic	Creation of an activity for the visitors of the Tech Museum to become part of a museum team and participate in the experience of engineering bacteria
	Genspace	Open Lab	Creation of the complete set of tools, knowledge and resources needed to develop a community laboratory (an *Open Lab Blueprint*, open source equipment, fluorescent protein genes, etc.)
	LA Biohacker s	Boot up a Genome	Use of Bacillus subtilus to incorporate the whole genome of Streptococcus thermophilus to demonstrate the use of Bacillus subtilus as a chassis to boot up an artificial genome
	London BioHacks pace	JuicyPrint, a 3D printer using bacteria to print cellulose forms on demand	Creation of a 3D printer fed with fruit juice to print 3D structures of bacterial cellulose (for tissue engineering, textile design, experimental art)
	SF Bay Area DIYbio	Real Vegan Cheese	Creation of vegan cheese by using baker's yeast (S. cerevisiae) to express cheese proteins and thereby create a substitute to milk
15	Genspace	SuperFUNd Gowanus!	Development of a biosensor to measure the pollution of the Gowanus canal and thereby give to the community real-time access to data on the state of the canal
	London BioHacks pace	DIY Brew Kit - Synbio Brewery	Development of an accessible kit containing a variety of brewing yeast strains for the purpose of *homebrewing*
	SF Bay Area DIYbio	BioSunBlock - Evolved Sunscreen for Bacteria	Studying cyanobacteria that have developed microbial sunscreens to be able to survive in environments with high radiation (applications: alternatives to toxic synthetic sunscreens, protection of terraforming bacteria, markers for genetic engineering)
	Wellesley TheTech	BacPack for New Frontiers: Designing Interactive Museum Exhibits for Synthetic Biology	Development of an interactive exhibition that shows the basic principles of synthetic biology to the public, with digital and wet-lab components
16	Denver Biolabs	An oxytocin diagnostic toolkit and other biotools for use in low-resource environments	Using yeast to detect oxytocin, a natural hormone that prevents postpartum hemorrhage during childbirth (and thereby reducing mortality)
	EMW Street Bio	Low Cost Labs: Machines That Grow	Development of a minimal set of tools necessary to carry out biotechnological processes
	Genspace	Tardigrades as a model animal for stress-resistance and developmental biology	Study of tardigrades (water bears) for their capacity to survive in extreme dry and cold environments
	Ingenuity Lab Canada	DNA assisted assembly of modular nanowires	Fabrication of modular nanowires from ADN with the advantage, when compared to traditional nanomaterials, to be cheap, biocompatible and with a flexible structure
17	Cadets2V ets	Affordable, Paper-based Assay For Detection Of Arsenic Contamination	Development of an affordable, portable and accessible means for testing arsenic contamination (by developing a plasmid that expresses the Green Fluorescent Protein)
	iTesla-SoundBio	Eliminating PCB pollution in the Puget Sound by genetically modifying E. coli	Decomposition of polychlorinated biphenyls – toxic substances that only degrade very slowly in the environment – by the bacteria Dehalococcoides mccartyi

	Moscow RW	Phytases piggy bank	Resolving the problem of the thermal destruction of the phytase of Citrobacter braakii during the production if granulated compounds for farm animals
18	Bio Without Borders	Blueblood	Development of a simple device to create horseshoe crab blood, in order to do a test for endotoxins
19	Bioriidl_Somaiya	Steriport - Making sterilisation and dispensing system portable	Development of an easy to use and portable system for sterilization
	Tacoma_RAINmakers	Improving the Agricultural Potential of Rhizobia	Development of the microorganism rhizobia as a potential alternative to chemical fertilizers

Table 1: Projects by community laboratories that participated to the iGEM competitions between 2014 and 2019

It has been argued (Meyer & Wilbanks, forthcoming) that four main families of activities can be distinguished within the DIY biology movement:

- projects dedicated to the development of low-cost equipment
- projects concerned with the environment and health issues
- projects that fall in the category of bio-art
- educational activities such as workshops, introductory courses, conferences, and classes

In addition to these four categories, an evolution towards professionalization and entrepreneurialization has also been observed in the movement. Bagnolini (2018, p. 101, my translation) writes that: “we must avoid [...] characterizing the movement of biohackers as a set of homogeneous practices.” Instead of a reductive and simplistic definition of biohacking, we must thus leave the definition of biohacking open and be attentive to the various trajectories, interests, practices, values, affiliations, identities, but also tensions and paradoxes.

According to a survey carried out in 2013 (Woodrow Wilson International Center for Scholars, 2013), DIY biologists work on average 7 hours per week on their projects, they are well-educated, more than half of them are fully employed (besides their DIY biology activities) and 25% are students. About two thirds are between 25 and 45 years old and three quarters are male. The number of DIY biologists is relatively difficult to estimate: the survey by the Woodrow Wilson International Center for Scholars (2013) had 359 respondents and on the DIYbio Google Group, in a discussion titled *How big is the DIYBio community?* (2017), several figures are given: "globally [...] something like 2000", "5,000 people in Europe". Trojok (2016, p. 155) states that within the movement we find natural scientists, engineers, artists, philosophers, most of which have university degrees. In a similar vein, Charisius et al. (2013, p. 23) declare that the movement comprises nerds, entrepreneurs, hackers, professional scientists, etc. As many people active in DIY biology are not amateurs or laypersons, we can talk about a "promised" citizen science, or a citizen science "in the making" (Meyer, 2013).

To the question that is often raised "are they really doing *science*?", we need to respond that DIY biology is an assemblage of various activities and practices – technical, environmental, entertaining, medical, artistic, educational – that do not necessarily translate into academic publications. DIY biology does not neatly fit into the category "citizen science" and has even been the subject of museum exhibitions (see vignette 1) and documentaries (Lassale, 2019; Schlichter & Karberg, 2012).

Exhibiting DIY biology in museums
The exhibition *Beyond the Lab – The DIY Science Revolution* was developed – and first shown - at the London Science Museum (from July 2016 to September 2016). The exhibition thereafter travelled to various

other countries. The exhibition focused on three related themes: citizen science, health hacking and DIY biology. The curatorial team chose to represent *individual* persons and their projects. "Equipped with low-cost sensors, smartphone apps and the ability to share information with communities online, these DIY science pioneers are challenging our ideas of who a scientist is and what science and our societies will look like in the future" the exhibition summary reads. In some countries, the exhibition was adapted to local contingencies by including additional examples (i.e. in Luxembourg, the exhibition featured a portrait of a local student and his invention: a helmet capable of measuring the force of an impact).

The exhibition *Biohacking: Do-it-yourself!* took place at the Medical Museion in Copenhagen from January 2013 until summer 2014. For the exhibition, the museum built a laboratory with the help of BiologiGaragen, a DIY biology laboratory in Copenhagen (see Davies, Tybjerg, Whiteley, & Söderqvist, 2015). The exhibition was built in a "garage" spirit: alternatives were sought to build the laboratory with a minimal budget. But there were many differences between a "real" DIY biology lab and the museum exhibit: a DIY biology lab provides a certain "aesthetic feel" and produces a "vibrant atmosphere," while the museum is organized in a more orderly way, and the challenge was to "maintain the impression of a real and vibrant hackerspace" (Sørensen, 2012). To display a laboratory in a museum, it is necessary to transform, adapt and rethink the laboratory. One may also wonder if, beyond the (temporary) transformations of lab into a "lab-in-the-museum," the museum itself can be transformed? According to the Director of the Medical Museion, "biohacking may have consequences for a museum. [...] I think we have much to learn about the culture of hacking [...] to help us rethink what a museum could be" (Söderqvist, 2013).

At the *Science Gallery* in Dublin, DIY biology was featured as part of an exhibition titled *Grow Your Own - Life after nature* (2013-2014). In order to do so, the Science Gallery installed a Community BioLab that was curated by Genspace. In this lab, various projects were presented and workshops and discussions organized. Members from Hackteria, (Art)ScienceBLR, La Paillasse, and MadLab were invited to organize workshops. La Paillasse, for instance, organized an event to produce biological ink by using bioproduction from soil bacteria. The production of biological ink was enacted in a specific form: it was not only displayed and celebrated, but workshop participants were taught how to use it. In other words, beyond the argumentation that ink can be made "yourself," the workshops delivered instructions for how to do so, with all the needed gestures, skills, and material practices.

Biohacking has also been featured in various exhibitions at *Ars Electronica* in Linz (Austria). The following projects have been displayed: the "DIY mobile gene lab" (developed by the Hackteria network), a collection of equipment to enable people to do biology at home; the "gene gun" (developed by Rüdiger Trojok), a device to inject gold particles coated with DNA into cells; and "Future Flora", featuring a DIY kit for vaginal flora (developed by Guilia Tomasello). The exhibition *Beyond the Lab – The DIY Science Revolution* has also been shown at *Ars Electronica*.

Vignette 1: Exhibitions featuring DIY biology

4. Examples of DIY Medicine

While DIY biology now enjoys a certain visibility, for DIY medicine and healthcare the situation is different. There are only very few laboratories specifically dedicated to it. It is rather around specific projects and issues, which are labeled "do-it-yourself" and/or "open source" medicine that practices are structured and collectives are formed. The *Nightscout Project*, for example, is dedicated to the development of mobile devices to measure type 1 diabetes (Greene, 2016). At the origin of this project is a father who, in 2013, developed a computer code to be able to remotely access the data of the glucose levels of his son. Since then, the project has attracted many users who have created a Facebook group with more than 23,000 members, developed sharing platforms, and made the source code open source.

Another project, developed at the Denver Biolabs in 2016 – and presented at the iGEM competition – is the *Oxytocin Diagnostic Toolkit* (see Table 1). This kit uses yeast to detect the presence of oxytocin, a natural hormone that prevents postpartum hemorrhage during child delivery and thus reduces maternal mortality, especially in poor countries. We can also mention the *DIY transcranial direct-current stimulation device* to stimulate the brain (Jwa, 2015; Lee, Hirschfeld, & Wedding, 2016); the development of an open-source ultrasound probe; the Amplino project, a portable device for detecting malaria; the Open insulin project, which develops an open source protocol for insulin production; Epidemium, a collaboration between La Paillasse and the Roche company to study large data sets on cancer; and EpiPencil (an epinephrine autoinjector) and the Apothecary MicroLab, both developed by the Four Thieves Vinegar Collective. Finally, let us also mention the *Open BioMedical Initiative*, a nonprofit initiative supporting the design and distribution of low-cost and open source devices such as mechanical hands and feet, as well as incubators. While these projects are praised for making care and medicine more affordable, more transportable and more accessible, concerns are raised about risks and regulations. For instance, "troubling is the overlap with patients who self-diagnose and self-medicate while rejecting evidence-based expert advice" (Ball, 2016, p. 555). And despite the promise of autonomy, new dependencies can be created: "The liberatory promise of the new DIY may be real, but in offering freedom from one dependence (on doctors or the physical plant of the clinic), it creates a new dependence on the app, the peripheral, and the speculatively financed startup firms that produce them" (Greene, 2016).

While these new dependencies can contradict the ideals of autonomy and empowerment, some collectives seek, nevertheless, to build attachments and links around certain health problems. This is the case of patients' associations, studied by sociologists Michel Callon and Vololona Rabeharisoa since the 1990s. These associations have often had to face the problem that rare diseases (also called "orphan" diseases) are little known by researchers and doctors, and the pharmaceutical industry is usually not interested in them. So while these associations have themselves produced scientific and medical knowledge about certain diseases – showing that "do-it-yourself" medicine is not such a recent phenomenon – they also aim to partner with health professionals, in order to better understand and cure diseases. The aim is therefore both epistemic – producing knowledge – and political: turning a problem into a priority for institutions and making it more visible.

5. Openness and Democratization

Openness, accessibility, transparency: these are some of the terms commonly used when describing DIY biology and, in particular, its ambition to transform science. The key argument put forward is that the life sciences (including molecular biology, genetics, but also medicine) should not be activities only carried out by professional researchers in their "ivory towers", but, instead, that other actors should also be involved (be they called "people," "citizens," "amateurs," etc.). The idea, simply put, is to *democratize* science. Democracy and democratization are, however, terms that need to be further problematized and unpacked to make them analytically operational. In order to "democratize" science, DIY biologists aim to open up biology spatially, technically, socially and economically.

First, there have been efforts to create spaces for experimentation – or "autonomous laboratories" as Esquivel-Sada (2017) calls them – outside the confines of traditional scientific institutions. 56 community laboratories have been created over the past 10 years, and there are numerous laboratories in people's private homes[1]. In a very spatial sense, then, biology has been "communalized" and "domesticated". Second, there have been efforts to make biology more accessible, via the scientific and technical equipment needed in laboratories. Among the growing list of alternative equipment, we can mention: the use of webcams instead of microscopes, of the *OpenPCR* machine instead of a conventional PCR machine, the *DremelFuge* instead of a centrifuge, and the construction of electrophoresis gels, magnetic stirrers, autoclaves, etc. In 2016, the *Essential Biohacker's Guide* was released. The guide, developed by a network of biohackers from Latin America, *Syntechbio*, lists alternatives for 25 techniques and laboratory tools (there are English, French, Spanish and Portuguese versions of the guide). The availability and mutability of these objects are an important factor in the development of DIY biology. According to Trojok (2016, p. 115), it is now possible through this alternative equipment to set up a functional laboratory in molecular biology for about 2,000 euros.

An important practice of DIY biologists is to work on "creative workarounds." That is, they try to find workarounds around objects in order to transform and combine them in novel ways, as well as around institutions, to circumvent established economic links between universities and industry. Such equipment is tinkered with and redesigned

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[1] It is, however, difficult to provide exact figures of the latter. In the above-mentioned 2013 survey, 83 respondents declared working in their "home lab". But given that 82% of survey respondents were from the US and only 10% from Europe, and given that between 2013 and 2019, the number of community labs has almost tripled, there are today most likely several hundred (if not more) laboratories in private homes across the world.

to serve as "convivial tools" (Illich, 1973), tools that can be more easily, more broadly and more flexibly used. Even more so, their "conviviality" is not only fostered by making them "open," but also by allowing them to be modified and improved. "DIYbio combines a sort of individual craftiness and self-determination *to do* things with a praxis in which things are left open, waiting for the next realization," writes Delgado (2013, p. 67).

The notion of "amaterialization" can be used to account for these constructions and transformations of laboratory equipment. This amaterialization is a process that is social (making equipment available to amateurs) and technical (transforming and recombining equipment). And this amaterialization is furthermore based on the co-construction of material equipment and "amaterial" versions of this equipment, that is, all the texts, pictures, videos and schemata that are used to ease their diffusion and reproduction (Meyer, 2015a). The relationships between amateurs and professionals are thus not only located *in* disciplinary fields or specific places (the usual sites to locate the amateur/professional boundary), they are also made possible *through* objects. The affordances of objects – as much as their mobility and their malleability – thus need to be taken into account in analyses of DIY biology.

Third, DIY biologists have developed their laboratories and equipment with a key social imperative in mind: that persons from all kinds of social and professional backgrounds can join laboratories and online discussions (such as the DIYbio discussion forum on Google Groups). Neither diplomas nor specific expertise is needed in order to become a member. Organizational structures are based on a "do-ocracy," not a meritocracy. While making this social openness explicit, DIY biologists frequently voice criticisms towards institutionalized science for its "countless rules, obligations, hierarchies, dependencies and pressures to succeed" (Trojok, 2016, p. 167, my translation). Delfanti (2013, p. 125) reports on their “distrust for bureaucracies.” This is also why accepting institutional funding is seen as problematic: “A part of the DIYbio community strongly upholds the philosophy of independence, freedom and decentralization, while fearing that accepting governmental grants may hinder their autonomy to speak freely or to pursue their work in their own choice and direction” (Nascimento, Pereira, & Ghezzi, 2014, p. 41).

Finally, DIY biologists also aim to democratize biology in economic terms. Community laboratories usually demand no fees, or at least very small ones, and one of the motives for building creative workarounds is to diminish the cost of laboratory equipment. DIY biologists can also save money by buying used equipment, and via donations (i.e. university laboratories or pharmaceutical companies donating their old equipment).

Despite presenting themselves as open and democratic, DIY biology laboratories might nevertheless face various difficulties and tensions. There have been reports of autocratic leadership, of visions not being shared among members, and of internal tensions regarding business models (Rivoire, 2017). Jen (2015) has noted that the dominant representation and promises of DIY biology are gendered: it is presented as a masculine universe of tinkerers and hackers, at the expense of feminine and feminist figures. Bagnolini (2018) has observed three problems within the biohacking movement: an overly strong focus on individuals and “self-made-men,” auto-experimentations[2], and the reduction of life to a machine. Concerning this last point,

[2] There have been recent controversies concerning people who have injected themselves various substances.

DIY biologists have in general a positive – and positivist – attitude towards GMOs and biotechnologies (Esquivel-Sada, 2017).

6. A Sociology of the "yourself"

When setting up a laboratory in a garage, kitchen or basement – and thereby domesticating biology spatially, technically, socially and economically – people depend on others interested in DIY biology, on scientific institutions, on the sharing of information, on the circulation of objects, on Internet platforms, on donations, etc. In other words, the "yourself" has to be connected. Because of this need for connectivity and collectivity, the term "yourself" might appear as a misnomer and terms such as "do-it-together" or "do-it-with-others" to be more appropriate. Yet, "yourself" symbolizes more than just a passive, individual person. "Yourself" stands for someone that engages with biology and literally *does* things, a self that is active and that is juxtaposed to other sites and scales of science production: the university, the institution, the enterprise, etc. The key idea is to make biology "personal" (Tocchetti, 2014). DIY biology thus aims to constitute a distinct and political form of self by providing people access, by enabling them to transform themselves into active producers of science, by making their bodies and environments more knowable, and by demonstrating that one can do it oneself.

Various scholars have noted that DIY biology can be analyzed in terms of *demonstrations*. Meyer (2013, p. 126) has argued that a DIY experiment is not only a demonstration of science per se, but also a socio-political demonstration in that it "attributes a social value, shows the feasibility of a process, and tries to convince and enroll actors". While looking at festivals, Maker faires and blog documentations, Tocchetti (2014, p. 96) states that demonstrations are not only about biological problems but that the spectator and/or reader becomes "the witness in an experiment aimed at demonstrating that everyone can do biology". In a similar vein, Delgado and Callen (2017) speak of "technical and political demonstrations".

7. Ethics and Governance

The politics of openness of DIY biology is at once celebrated and dreaded. On the one hand, it is praised for empowering citizens, for fostering open innovation, for providing new means for education, and for being inclusive. Optimist accounts often compare DIY biology to the Home Brew Computer Club and to Steve Jobs – a promissory comparison that brings side by side a familiar success story and a story-in-the-making, and offers a narrative of innovation and revolution. On the other hand, DIY biology has also raised concerns about security, safety and regulation. When the movement emerged, a number of media articles portrayed it in negative terms, and pondered on the potential threat of bioterrorism. DIY biology has been examined in several national reports (in the US, the UK, the Netherlands, Germany, France, etc.) and international reports (i.e. by the United Nations Interregional Crime and Justice Research Institute), usually in relation to synthetic biology. While these reports deal with very similar concerns – ethics, governance, risks, safety, regulation – they nonetheless reveal differences between countries in terms of regulatory environments, visibility/invisibility of surveillance by secret services, and policy and funding recommendations. In recent years, the use of new gene editing techniques, such as CRISPR/cas9, has raised additional concerns about the control of the fabrication of synthetic organisms.

There have been different kinds of responses from the DIY biology community to such safety and security concerns. The first response is discursive: responses by practitioners highlight that DIY biologists do not work with dangerous material and that potential terrorists do not need DIY biology to meet their aims. The second response has been ethical, by collectively establishing a code of ethics. The European code of ethics, first drafted in 2011, states that practitioners should “emphasize transparency,” “adopt safe practices,” “promote citizen science and decentralized access to biotechnology,” “respect humans and all living systems,” etc. (see Figure 1). The American code of ethics is similar, but shorter: it doesn’t include principles such as modesty, respect and responsibility, and it can thus be considered as being weaker than the European one (Eggleson, 2014, p. 191). The ethical principles of the DIY biology movement are similar to those of the *Gathering for Open Science Hardware* (GOSH) movement: GOSH “is accessible, makes science better, is ethical, changes the culture of science, democratizes science, has no high priests, empowers people, has no black boxes, is impactful tools, allows multiple futures for science.”

The third response has been practical: on DIYbio.org, a portal has been set up through which people can ask questions about safety to a panel of biosafety experts and members of a professional association of biosafety; DIY Bio Europe (a network that was launched in 2012) has developed “Community Biolab Guidelines,” and several laboratories have developed internal guidelines or courses dealing with safety.

DIYbio Code of Ethics
Draft from the European Delegation
09/07/2011

Transparency
Emphasize transparency and the sharing of ideas, knowledge, data and results.

Safety
Adopt safe practices.

Open Access
Promote citizen science and decentralized access to biotechnology.

Education
Help educate the public about biotechnology, its benefits and implications.

Modesty
Know you don't know everything.

Community
Carefully listen to any concerns and questions and respond honestly.

Peaceful Purposes
Biotechnology must only be used for peaceful purposes.

Respect
Respect humans and all living systems.

Responsibility
Recognize the complexity and dynamics of living systems and our responsibility towards them.

Accountability
Remain accountable for your actions and for upholding this code.

Figure 1: The European DIYbio code of ethics, drafted in 2011 in London (source: DIYbio.org)

The fact that some DIY biologists have been in touch with the FBI has been discussed in numerous texts (Charisius et al., 2013; Ledford, 2010; Meyer, 2015b; Tocchetti & Aguiton, 2015; Wolinski, 2016). In recent years, the FBI has developed a proactive attitude, presenting itself as the “new FBI.” For example, the FBI organized a DIYbio outreach workshop from June 12 to 14, 2012 near San Francisco. Around forty people attended, including FBI members and DIY biologists from around the world. Although the event was organized by an American intelligence service, many European DIY biologists were invited and agreed to participate. Representatives from Paris, Copenhagen, Berlin, Helsinki, London, Manchester, Amsterdam and Prague were present (but numerous persons also declined the invitation). During the workshop, the FBI stated that it wanted to “work with” DIY biologists, viewing them as “partners” in a “positive relationship.” While security and responsibility remain its main concerns, the FBI aims to distinguish between “white hats” and “black hats,” so that the DIY biology community is “protected against harmful actors.” The FBI also distributed a set of didactic cards called “biosecurity outreach cards” with information on various bacteria and viruses, such as Ebola, adenovirus and smallpox. The stance of the FBI was that DIY biologists should themselves carefully monitor and report suspicious activities. The reaction of the DIY biology community to the FBI’s strategy can be summed up as follows: while for US practitioners, it is seen as obvious and normal to collaborate with the FBI, the European delegates were suspicious, skeptical and irritated (Charisius et al., 2013, p. 196-202). What the relationship between DIY biologists and the FBI also reveals is that the boundary between experts and suspects is not clear-cut, and that biohacking can be differently interpreted (Tocchetti & Aguiton, 2015).

Other nuances and differences should be highlighted. For instance, regulation is less strict in the US (where it easy to produce GMOs in a DIY biology laboratory) than in Europe (where it is very difficult to get an authorization to produce GMOs outside scientific institutions[3]). Further, in Europe there are stronger collaborations between DIY biologists, artists, and designers than there are in the US (Seyfried, Pei, & Schmidt,

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[3] Among the exceptions we can count laboratories in Graz (Austria), London (UK) and Cork (Ireland).

2014). It is also important to note the differences between the Global North and the Global South, as made clear by the following statement by the cofounder of Africa Open Science and Hardware, Thomas Hervé Mboa Nkoudou: “People engage in Western countries, because it’s like a hobby. But in Africa, it’s different. People are engaged in this movement to survive, to find a job, to solve a particular problem. [...] There are many hospitals in rural zones [...] in Africa, which don’t have even the small equipment to run small diagnoses for patients. So biohacking can be helpful” (cited in *The Commoners Scientist* (Lassale, 2019)).

8. Economics and Valuation

Discussions do not only concern the ethics and (geo)politics of DIY biology, but economics and funding as well. We see both non-market and market rationales at work. In its purest form, there is a logic of “do-it-without”: DIY biology is often portrayed as a reaction against pharmaceutical companies, standard/expensive equipment, patents and, in general, against everything that keeps knowledge from being freely shared. Yet, DIY biology relies – at least partially – on markets and industries: by buying used equipment from commercial websites, tools and products from supermarkets, or seeking and accepting donations from companies. Also, various sources for funding DIY biology projects have been sought, be it via membership fees, crowdfunding, grant funding, or from local municipalities. There are also several entrepreneurial projects that have developed out of DIY biology (see *OpenPCR, Pearl Biotech, LavaAmp, Ginkgo Bioworks, Bento Lab, PILI*).[4] Scholars have therefore talked about a “cooptation”

[4] The *DIYbiosphere* initiative currently lists 32 start-up linked to the DIY biology movement.

(Delfanti, 2014) and “recuperation” (Delfanti & Söderberg, 2018) of the movement. The potential relationships and co-existence - or, conversely, tensions and ruptures – between non-market and market rationales will be interesting to follow as the movement further develops.

Different forms of *valuation* can already be observed when looking at the moments and places where DIY projects are valued (such as during a competition or in front of potential investors) (Meyer & Wilbanks, forthcoming). On the one hand, there are non-market valuations of the movement, with the promotion of social, ethical and cultural values (such as citizenship, democracy, openness, sharing, education, empowerment, etc.). On the other hand, there are also market valuations: projects that turn into start-ups; projects that, during a pitch in front of investors, require several hundred thousand euros; partnerships with private companies. These valuations are distributed and heterogeneous: products, practices, principles and places are valued at the same time (Meyer & Wilbanks, forthcoming). They aim to generate an “interest” in a triple sense of the word: a general interest (i.e. a common and public good), an interest for a given public (its curiosity and awareness), and a monetary interest (by asking public or private actors to contribute financially to projects).

9. Conclusion

DIY biology and medicine are based on various practices and logics: amateur and DIY practices, the ethics of hacking and open source, the drive to domesticate molecular biology and genetics, the ideal of participation and citizen science. This democratization is a process that is at once spatial (construction of new spaces), technical (creative workarounds around equipment), social (establishment of accessible networks/laboratories) and political. It is therefore through their practices, gestures and questions – tinkering, experimenting, demarcating, working around, amaterializing, ethicizing, comparing, valuating, etc. – that we need to grasp DIY science.

In the academic literature, several facets of DIY biology have already been quite thoroughly addressed: its history (Curry, 2013; Kelty, 2010; Tocchetti, 2014), materiality (Delgado, 2013; Meyer, 2013; Meyer, 2015a), identity (Esquivel-Sada, 2017; Meyer, 2016), ethics (Bagnolini, 2018; Eggleson, 2014; Keulartz & van den Belt, 2016), politics (Delfanti, 2013), and economics (Delfanti & Söderberg, 2018; Meyer & Wilbanks, forthcoming). The issues of the democratization of biology, as well as the links between hacking, biohacking and synthetic biology, have been addressed in nearly all the texts cited in this chapter.

Several issues have, however, not been researched in great depth: While most work has looked at the various laboratories, devices, projects and discourses that have been created, much less is known about the failures, dead-ends and abandonments within the movement. An exception is the book by "experimental" journalists Charisius et al. (2013) that provides some insights into the difficulties and failures that can be encountered. But an analysis and theorization of these difficulties is still lacking. Research on the fragilities, instabilities and ambiguities within the DIY biology movement would be a key contribution to the literature.

The geographical scope of academic work has been limited to either the US or the European context. Kera (2012, 2015) is among the few scholars to have looked into Asia and the Global South as other sites of DIY biology. Further research could thus look at the ethics, politics and practices of biohacking in non-Western contexts in order to provide more comparative and situated accounts of DIY biology.

The fact that many DIY biology laboratories are engaged in educational and outreach activities has not been a research topic thus far. Apart from the examples from the museum world mentioned above (see vignette 1), only one paper explicitly addresses the topic of education (Kallergi & Zwijnenberg, 2019). The authors of this paper examine a module that they teach on the ethics of biotechnology – a module in which they use hands-on participation as a pedagogical means to reflect upon responsible innovation. However, the many workshops, visits of school classes, conferences, and introductory courses organized by DIY biology laboratories still need to be analyzed more systematically and sociologically.

Academic work on DIY biology has so far mainly focused on four related themes: its social and material architecture, its genealogy and history, its ethical and political characteristics, and its entrepreneurial dynamics. The wider geographies, fragilities/instabilities, and relations to the public are topics that deserve further inquiry.

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