Distributed Biotechnology

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In the last two decades, an array of do-it-yourself biology groups, biotech start-ups and community labs have emerged in Europe, America, and Asia. These groups and spaces share the vision of a "distributed biotechnology" and are part of broader transformations of the relation between technological and scientific change and society. Distributed biotechnology includes amateurs as well as an emergent set of companies that provide laboratory equipment and digital platforms designed to foster citizen contribution to biotechnology research. It differs from traditional forms of citizen science, as it draws on elements from hacker cultures and adopts molecular biology as its main scientific framework. The term "distributed" means that actors envision a biotechnology free from centralized control. They imagine biotechnology as personal, and the aggregation of individual efforts as technically and socially meaningful. Thresholds to access are relatively low, as distributed biotechnology's spaces are open to amateurs and its techniques sometimes rudimentary. Finally, connections between different actors are created and maintained through the circulation of people, materials, and information.

Regardless of the hype that surrounds it, the output of distributed biotech tends to be relatively far from any "revolutionary" scientific breakthrough. What makes it worthy of analysis is the way it imagines and implements practices that construct biotechnology as *open*, *personal*, and oppositional towards biomedical research incumbents. Distributed biotech is characterized by a perceived, and in some cases sought-after independency from, if not opposition to, incumbent institutional actors, such as corporate and university labs. Indeed, different actors share the goal of broadening life science research beyond the limits of traditional institutional laboratories. Yet, distributed biotechnology seems to emerge out of a complex relation with incumbent institutional actors, rather than in opposition to them. Also, it intersects deeply with the broader neoliberal economy of science and its innovation and justification regimes. The definition of "distributed" aims at unpacking some of these ambivalences, as it signals a plural approach to biotechnology while avoiding the lexicon of democracy implicit in definitions such as "participatory" or "citizen" science. The term also highlights how the aggregation of individual scientific and technological practices is seen as increasingly efficient, which resonates with neoliberal ideas about the market's spontaneous order. While distributed biotech affects the distribution of power within the life sciences, in many cases its endeavours are hardly emancipatory. Rather, they are geared towards the creation of new forms of value. This reminds of contemporary open science's role as a site where new forms of appropriation of the value produced by scientific research are experimented with and established (Birch 2012, Tyfield 2013).

Citizen and amateur science have long been used as examples of the permeable boundaries of scientific knowledge production. Yet it is only since the first draft of the human genome was sequenced and published in 2000 that the diffusion of equipment for DNA extraction, sequencing, recombination, and eventually synthesis has become available and affordable. Furthermore, distributed biotechnology emerged from political and cultural transformations. In fact, it is based on the availability of relatively cheap and accessible equipment such as PCR machines, centrifuges, vectors, or microscopes; the emergence of community laboratories explicitly directed towards amateurs; the broad availability of shared information, such as biotech protocols or genetic sequences, through open access databases; and the influence of digitally-mediated participatory cultures within science. The actors that compose it are arguably quite diverse and heterogeneous, but they tend to co-evolve within networks that exchange resources and information. Community labs allow individuals to tinker with basic molecular biology processes, such as DNA extraction or bacteria genetic modification. Some labs have access to more advanced equipment, such as polymerase chain reaction machines or genetic sequencers. Start-ups might aim at engineering yeast to produce commercially interesting molecules such as THC, or develop web-based platforms for distributed genetic research. Groups work to produce molecules as different as insulin and hormones in order to escape the monopoly of pharmaceutical companies.

These phenomena have been described using terms such as "craft." This highlights the scalability of biotech towards small-scale interventions; these are characterized as low cost and accessible to amateurs, in opposition to the professionalization of mainstream biotech (Roosth 2011). Concepts such as "kitchen" or "garage" biology touch upon the same idea while contributing to the understanding of how these forms of amateur biology are gendered (Jen 2015). Scholars have referred explicitly to DIY biology as a step towards an increased democratization of biotechnology. For example, through processes of "domestication" or "demystification" that question the separation between expert and amateur (Frow 2015, Meyer 2013, Wolinsky 2009). Since the mid-2000s, scholars analyzing the rise of phenomena such as DIY biology have also focused on the relation between distributed biology and hacking, thus adopting the term "biohacking" as an umbrella term referring to different forms of distributed intervention in the life sciences

(Davies et al. 2015, Delfanti 2013, Kelty 2010). This designation reflects the self-ascribed genealogy that many DIY biologists or entrepreneurs construct. Furthermore, it allows scholars to highlight the ambivalent relation that DIY biologists and entrepreneurs have with scientific and biomedical research institutions and corporations. Hacker cultures encompass a diverse set of practices and values. What they have in common is a playful approach to information technologies, undaunted by hierarchies and organized around the idea that the skilled many can achieve change through a politics of technology (Coleman 2012, Soderberg 2013). Using the term biohacking, actors and scholars alike draw parallels between biotechnologies and computers, imagining technology that intervenes in living matter will become "personal" and open to a mass market. In the 1970s, the personal computer emerged out of attempts at liberating computing technologies from the control of academic, military and industrial actors. This "liberation" was aimed at the political appropriation of communication tools. But it was also geared towards the creation of a new market for mass-produced computers (Turner 2006). Ideologies of technodeterminism and libertarianism emerging from the Silicon Valley influenced advanced capitalism at large with their visions of the free technological entrepreneur as the engine of progress and wealth creation (Barbrook and Cameron 1996). The groups, companies and spaces that compose distributed biotech have emerged out of parallel histories. Yet they share a dissatisfaction with the current political economy of biomedical research and the idea that it can be overcome by making biotech open, personal and distributed. In this sense, they imagine that incumbents such as Monsanto or Novartis may be today's biotech equivalent of what IBM was for 1970s hackers: bureaucratic monopolies that can be disrupted through an expansion of both technologies and markets.

Distributed biotech has been imagined and practiced in artistic milieus that aim at opening up recombinant DNA techniques to critique the dominance of multinational corporations in the biotechnology sector. In a parallel genealogy, distributed biotechnology has also been constructed as a form of "personal" technology by actors from the industrial and academic world. This created a wave of community labs first, and start-up companies that attempt to foster a new market for biotech equipment and services later. The development of "openness" as a set of organizational and political characteristics, such as open source information exchange, open citizen participation, and open markets, is a crucial foundation of distributed biotech. The above factors aim at providing new sources of public trust for biotechnology – *re-moralizing* it – by constructing it as consumer-friendly, non-proprietary and participatory. By creating new entrepreneurial subjects and exploiting outsourced labor, distributed biotech may contribute to broader phenomena of market and labor deregulation. Finally, distributed biotech is subject to processes of institutionalization that integrate its technologies and practices within new contexts while also diluting their political potential. As it matures, it is increasingly participating in a reconfiguration of the relation between practices of knowledge production and the social order.

Critique of the biotech industry

Since the early 2000s the possibility of re-appropriating biotech through distributed and participatory research has been explicitly presented as a critique of the political economy of corporate biotechnology. *Bioart* has long been used as either an educational tool or a celebration of biotech development through the engagement of different publics. In other cases, artists aimed at using biotech tools and practices to criticize the biotechnological industry for its lack of transparency, reliance on intellectual property rights, and environmental impact. Groups related to hacker cultures struggled to create permeable spaces where political and artistic explorations of biology could express confrontational practices that addressed the power of the industrial and academic sectors.

Among other artists and collectives using biotech-based art as a form of political intervention, the Critical Art Ensemble (CAE), a United States art collective, stands out as one of the most influential cases. In the early 2000s, CAE designed several citizen science performances that were explicitly framed as oppositional to the biotechnological industry. CAE called for the emergence of a "contestational biology" as a tool to challenge the structures of power within market relationships and the role of biotechnology in today's capitalist societies – in their words, "molecular capitalism" (2002). During CAE's *Free Range Grain* public performance, for example, the art collective allowed the public to test foods through basic molecular biology techniques. Distributing the means to search for genetically modified crop contamination was meant to counter the disempowerment produced by the role of multinational corporations in agrobiotech. In its proposal for new forms of "fuzzy biological sabotage," CAE envisioned that genetic hacking could provide activist groups with tools to challenge the structures of power and the role of biotechnology in today's capitalist societies. These politicized activities in the artistic sphere continue nowadays, especially in Europe and Asia. Art collectives such as the Switzerland-based group Hackteria routinely organize workshops that aim at re-appropriating biotech. The processes used within these practices can be quite basic. For example, they may rely on teaching to build a DIY gel electrophoresis chamber in an IKEA tupperware. Yet, these groups tend to represent the political economy of biotech as a site of conflict and contestation, while its re-appropriation through DIY approaches is constructed as a form of tactical intervention (Magrini 2014). Political activism in this field tends to be concerned with the political economy and hierarchies that characterize the biotech industry, as well as the possible emancipatory uses of re-appropriated biotech processes and materials, such as citizen environmental research. Feminist groups emerging out of hacker and punk cultures, especially in Europe, are mostly concerned with the collective appropriation of biotech to create spaces of autonomy from state-controlled medical systems. Groups such as GynePunk or Gaudi Labs, for example, attempt to produce open source tools that can be used to perform gynecological medicine. Other projects, such as Open Source Gendercodes, engineer tobacco plants to produce hormones that can be used to cross gender boundaries and that are "collectively owned".[1]

Other forms of critique emerge from the need for a new kind of scientific universalism based on people's access to biological research. Written in the US in 2010, the *Biopunk Manifesto* introduces critiques of the monopoly of institutional biotech while implementing the idea that freedom of research should be equal to freedom of speech: "We reject the popular perception that science is only done in million-dollar university, government, or corporate labs; we assert that the right of freedom of inquiry, to do research and pursue understanding under one's own direction, is as fundamental a right as that of free speech or freedom of religion" (Patterson 2010). This and other, similar, documents point out a problem in the distribution of power in biology. At the same time they somewhat conflate the democratization of science with access to its technologies and knowledge. This rhetoric has been inspirational for subsequent waves of biohackers. Yet the role of these attempts at critiquing the political economy of contemporary biotechnology should not be overrated. Based on ethnographic research, scholars have balanced descriptions of politicized distributed biotech, highlighting areas of political ambivalence (Delfanti 2013, Tocchetti 2014). Through somewhat ironic definitions such as "outlaw biology," scholars have recognized a willingness to perform participatory biotech outside established institutional frameworks, meanwhile stressing its limited scope and nuanced genealogy (Kelty 2010). For example, through the construction of the need for biosafety regulation, distributed biotechnology has been prompted to engage in negotiations with state actors to confront issues of environmental safety. This is the case for the DIYbio network in the United States and the relationship it built with the Federal Bureau of Investigation (FBI) in the early 2010s in order to present DIY activities as legitimate and safe. This scenario generated friction with certain European groups. Yet, it also helped construct distributed biotechnology as a promissory field while redefining the risks associated with it as scientific and financial rather than, for example, linked to bioterrorism (Tocchetti and Aguiton 2015).

Biotechnology becomes personal

Distributed biotechnology is rooted in attempts at transforming molecular biology into a *personal* technology by making biotech equipment, processes and knowledge accessible to individuals. The idea of making technology personal is strictly tied to utopian visions of a decentralized, egalitarian and free society that resonate with the idea of a "digital utopianism" that is hegemonic in Silicon Valley cultures (Turner 2006). Distributed biotech constructs biology as produced by and for the people, and thus envisions "unlimited participation" in science (Reardon 2013, Tocchetti 2014). Yet the scope and goals of distributed biotech are not unlimited but rather geared towards certain groups and specific ends. Furthermore, personal biotechnology produces neoliberal entrepreneurial subjects whose proactive and individualized approach to biotech, based upon exchange freed from centralized command (Foucault 2008), becomes meaningful through the aggregation of plural contributions into an emergent order rather than through collective deliberation practices.

In the mid-2000s, a new wave of efforts to imagine and practice forms of distributed biotechnology emerged in academic departments. It then spread to both amateur communities and entrepreneurial milieus. This genealogy is based on the construction of new mechanisms that intervene in living matter, a broadened inclusion of new constituencies, and the growth of an infrastructure of distributed biotechnology laboratories, tools, and digital platforms. These efforts are founded upon attempts dating back to the early 2000s that sought to construct biological matter as a composition of standardized, interchangeable parts. These early processes came to define what we now call "synthetic biology." The Registry of Standardized Biological Parts is a database of BioBricks: genetic parts that can be assembled into full DNA sequences. Proposed by U.S. technologists and geneticists such as Tom Knight and Drew Endy, this project was coupled with platforms for open information exchange, such as the OpenWetWare wiki. This is an online service for sharing information about synthetic biologicy protocols and materials. These approaches tackle DNA and living matter not just as information, but also as pliable material which, like software, can be made hackable and shareable (Calvert 2010, Roosth 2011). This is related to a broader shift of the scientific enterprise towards computation as a core tool for life science–research, as well as a cultural framework with epistemic value (Kay 2000). Early synthetic biology was also the result of a willingness to challenge the idea that biotech must be based on the strict enforcement of exclusive intellectual property rights. Furthermore, attempts at standardizing components of biological matter components into interchangeable parts are part of a project of further industrialization of biotechnology. Finally, these changes fostered the opening of synthetic biology to distributed contributors (Hilgartner 2012, Bogdanov 2016). For example, the International Genetically Engineered Machine (iGEM) competition, hosted by MIT since 2003/2004, is an international competition in which teams of students from universities or countries use BioBricks to generate synthetic organisms. The aim of iGEM is the "open and transparent development of tools"[2] for biotech. Inspired by free and open source software and yet geared towards molecules and cells rather than bits, such sites were foundational in the birth of contemporary synthetic biology (Roosth 2011). Combined, the informatization, standardization, and open sourcing of synthetic biology provided a foundation for its expansion towards distributed forms of biotechnology and also fostered its commodification. Scholars have argued that experiences such as iGEM have spread a neoliberal entrepreneurial culture among participants (Aguiton 2014). This newfound culture cultivated an approach to living matter aimed at its transformation and commercialization.

Later, the idea of expanding access to synthetic biology included opening it up to new actors, such as individual entrepreneurs. In a 2005 *Wired* article, the US biotechnologist Robert Carlson called for new forms of distributed biotechnology that he referred to as "garage biotech" – referencing the Silicon Valley garage, depicted in many accounts of the history of computers as a core site of disruptive innovation ("Splice It Yourself", 2005). Carlson's article, along with other conceptualizations of biotech as accessible from non-institutional spaces, such as garages or backyards, were based upon the idea that biology had witnessed the emergence of the same premises that have allowed for the existence of online peer-to-peer production. Such premises included the availability of affordable hardware in forms of equipment and machinery; an online infrastructure for sharing protocols and data; collaborative software services; the broad availability of easily accessible public data and information; copyleft licenses that allow content reuse, modification and redistribution; and a culture of participation (Delfanti 2013, Meyer 2012).

Under this banner, early attempts such as the 2007 Open Biohacking Kit or the website biopunk.org (Bogdanov 2016) preceded the birth of DIYbio (do-it-yourself biology), a loose network of amateur biologists launched in Boston in 2008. DIYbio's founders were already actively involved in projects such as the iGEM competition and the Personal Genome Project. With the launch of DIYbio, they aimed at fulfilling the idea of a distributed, citizen biology led by non-experts – a "science without scientists" (Bobe 2008). Initially organized around a local group and a website, DIYbio has grown to represent the most significant early example of a distributed biotechnology community. DIYbio was formed to make biology accessible to *anyone*, regardless of formal education, technical skills or institutional affiliation. Under the umbrella of DIYbio, distributed biotech has indeed attracted a flow of individuals to biotechnology and other forms of life science research. Following its launch, a series of spaces for the development of distributed biotech started emerging in urban environments. Predominantly white and male, at least initially, amateur biologists have formed groups in many cities in North America and Western Europe, with a recent expansion in Asia and South America (Kera 2012, Meyer 2013). These groups now tend to include individuals with varying backgrounds. In many cases, a core constituency is composed by biology students, while other participants are computer programmers interested in applying information science to living matter. A minority of individuals are interested in art and design. In a significant number of cases, DIYbio participants seem to be biologists frustrated with the hierarchies and lack of freedom experienced in their professional lives (Delfanti 2013, Delgado 2013, Grushkin et al. 2013, Landrain et al. 2013). Since the foundation of DIYbio, participants have constructed this form of distributed biotechnology as independent from, although not opposed to, scientific institutions.

While early rhetorics depicted distributed biotech or biohacking as happening in kitchens, garages or backyards, the spaces of early laboratories were rather community spaces or hackerspaces. Such labs include GenSpace in New York (2010), Biologigaragen in Copenhagen (2010), Biocurious in Sunnyvale, California (2011), La Paillasse in Paris (2011) and Counter Culture Labs in Oakland (2014) (Delfanti 2013, Meyer 2013). In many cities, such as Seattle, Los Angeles, Copenhagen or Toronto, DIY biolabs were initially formed as "wet" corners within existing hackerspaces or makerspaces. Although characterized by different local and political cultures, the shared goal of these and other *biohackerspaces* is to provide community-run labs where non-professionals can have access to basic equipment such as glassware, centrifuges, polymerase chain reaction machines, or gel electrophoresis for biological research. In most cases these spaces are self-funded through donation or participants' monthly fees. However, some early labs were equipped with scrap or second hand equipment. Activities can be quite diverse and include basic biology experiments, such as cell cultures, as well as more advanced processed based on recombinant DNA, such as the engineering of bioluminescent bacteria or the production of "real" vegan cheese obtained by engineering yeast to produce milk protein. DIYbio participants and an emerging network of start-up companies soon started designing and producing open source lab equipment for recombinant DNA technologies, such as the early flagship projects Open Gel Box or OpenPCR. This DIYbio open source technical equipment, now expanded to include many DIY machines produced by biohacker groups, is designed to be directly transformable by individual users and based on shared protocols (Kera 2012). Further technological evolutions have produced affordable and consumer-friendly DIYbio tools that are not technically open source and thus more difficult to transform, upgrade and reproduce, while aimed at broader constituencies. This is the case of portable, laptop-sized biotech labs commercialized in the mid-2010s: Bento Lab includes a PCR machine, a centrifuge and a gel electrophoresis unit and presents itself as part of "a mission to make bio available to all;"[3] and the Amino is a unit for cell cultures that runs pre-determined "apps," that is, kits for synthetic biology production. Companies such as The Odin commercialize lab supplies and equipment such as yeast or bacteria CRISPR kits that allow DIY precision genome editing. Since early attempts at producing open source tools, distributed biotech has thus been enriched by the launch of start-up companies that have tapped into an emerging, although small, market for personal biotech products (Palmer and Jewett 2014).

Although it first emerged out of an academic context, the idea of DIYbio becoming a personal biotechnology is the product of a more complex history that inculdes its relationship with the maker movement. *Make Magazine*, arguably one of the flag-bearer publications of the US maker movement, has been instrumental in constructing biology as a personal technology offered to new constituencies (Tocchetti 2012). This mirrors discourses about the 1970s as a time when it was first imagined that computers could be personal technologies fit for mass commercialization rather than technologies targeted at bureaucratic institutions, such as the military or universities (Turner 2006). Due to the inclusion of DIY biology within a broader maker culture, biohacking has become a site in which biotechnological interventions on life are based on small-scale technology and bestowed upon the hands of a new entrepreneurial subject, the maker (Tocchetti 2012). This change, embodied by a series of start-up companies working within distributed biotech, contributes to claims that a personal biotech should be constructed as complementary, rather than in opposition to, corporate and academic incumbents. In this renewed context, the political economy of corporate biotech is to be challenged only insofar as it is tackled as a problem of industry concentration. Actors tend to comply with state regulations on environmental and laboratory safety while expressing grievances towards obstacles to market-based interventions.

Openness as a new moral ground

Distributed biotech adopts a specific set of forms of "openness" as the main framework that governs decisions about which information must be circulated freely, who can access DIY labs, and who should be able to design and commercialize biotech artifacts or services. Spilling from free and open source software into areas as heterogeneous as technological development, journalism, and politics, openness has come to represent a crucial driver of legitimization of contemporary societies (Tkacz 2015). In science, this is hardly a radical change. With the idea of a *moral economy* of openness that underpins scientific research, modern science has been conceptualized as based upon a set of social values that underlie and govern exchange within a scientific community. In particular, this relates to property, credit, and access (Kohler 1994). These values have influenced contemporary research. For example, the exchange of genetic parts in open source synthetic biology is an evolution of earlier moral economies that underpinned the 20th century exchange of basic tools of research, such as model organisms like *drosophila* (Kelty 2012). Modern "open" science is also the result of a specific social contract, with its incentives and arrangements aimed at sustaining and legitimizing the scientific enterprise (David 2000). This contract includes references to the boundaries and role of public participation to scientific research. The increasing use of computational technologies for contemporary research in biotechnology implies not only an epistemic change, but also a reconfiguring of how morality is constructed through openness. Thus, the moral economy of openness that sustains distributed biotech seems to represent a further step towards the construction of public legitimization.

Openness, in other words, has become a crucial *test* of public morality (Boltanski and Thevenot 2006). The re-moralization of the biotech industry, particularly in the case of synthetic biology (Tyfield 2013), occurs in the wake of political contestations over research privatization and corporate monopolies in both agrobiotech and medical biotech, especially resulting from the introduction of mass-produced GM organisms in agriculture in the 1990s (Bauer and Gaskell 2002). The resulting crisis of public trust in biotech was related to the rise of intellectual property rights owned by multinational corporations, the commodification of knowledge produced by public universities, and a lack of political control of biotech's goals and methods. On the contrary, the exchange of information, tools and materials that culminates distributed biotechnology is based, albeit in different forms, on three complementary dimensions of openness: open source information, open participation, and open markets. The idea that a new kind of biotechnology could be modeled after free and open source software meant that it could be distributed not only by adopting technical open source arrangements such as open licenses, but also by including new, non-expert individuals. Thus, on the one hand, openness refers to the use of alternative forms of property and control, adapted from the software world, that help make information and processes available to distributed individuals. On the other hand, broad new groups of participants are created through a political form of openness that grants access to distributed biotech while making power susceptible to scrutiny and transformation, thus reinventing the somewhat lost universalism of contemporary biotechnologies (Kelty 2010).

The final form of openness refers to the creation of open markets for consumer-friendly products that new economic actors can develop and commercialize. These actors include start-up companies or community-based actors that compete against the market concentration pharmaceutical and agrobiotech corporations represent. Thus, openness is a multifaceted element rooted in technical, legal and moral decisions (Bogdanov 2016). Through its use of openness, distributed biotech is constructed as non-proprietary, participatory, transparent, user- and consumer-friendly, as well as opposed to monopolies and market concentrations. This makes distributed biotech a site where tensions towards a collective and participatory biology coexist with forms of commercialization within a common framework of public morality. While several authors have denounced the ambivalence of this project (Birch 2012, Deibel 2014, Delfanti 2013, Tyfield 2013), the incorporation of these multi-faceted forms of openness into the moral economy of distributed biotechnology has left the field relatively prone to new reconfigurations.

Institutionalization and commercialization

Despite recurrent rhetorics that construct distributed biotech as autonomous from corporate and academic institutions, processes of increasing institutionalization are at play. Contrary to accounts that present new forms of distributed biotech, such as DIY biology or biohacking, as a re-appropriation of life science research, some authors state that the trajectory of distributed biotech is one of further integration within the industrial, academic, and educational sectors. Indeed, distributed biotechnology is intertwined with academic and corporate laboratories, and it remains technologically dependent from its mainstream counterpart (Delgado 2013). For example, DIYbio communities rely on these labs for skills, equipment, and tools. According to surveys and ethnographic accounts alike, many DIYbio practitioners also work in academic, corporate or government labs (Grushkin et al 2013, Seyfried et al. 2014). These members constitute a core group that provides skills and resources while leading the development of biohackerspaces, community labs and start-ups. Also, academic institutions appear to have a growing interest in funding DIY biology or establishing partnerships with it following a trend of inclusion that is increasingly common among forms of citizen science (Grushkin et al. 2013, Landrain et al. 2013).

Processes of institutionalization typically studied in social movements have been observed in groups that use alternative technological innovation as a tool for social change. These alternative technologies and processes are often developed with the help of companies that work in close relation to non-market actors. The technologies are eventually incorporated by the industry, which transforms and adapts them according to its needs (Hess 2005). One standard example is the rise of open source software as a market-friendly evolution of free software. Institutions tend to partially adopt alternative technologies and socio-technical practices while simultaneously altering and neutralizing them. These dynamics of co-option are at play with hacking, which evolves in symbiosis with industry partners and experiences cycles of institutionalization (Delfanti and Soderberg 2016). Organizational practices geared towards the fostering of distributed innovation and derived from hacker cultures, such as hackatons, are subject to uptake by institutional actors, as they can be used to produce and celebrate a neoliberal entrepreneurial subjectivity that resonates with Silicon Valley cultures (Irani 2015).

The emergence of start-up companies inspired by biohacking, especially in the US, reflects broader market-based shifts, as science and health are increasingly mediated by private corporations through processes of individual consumption. In fact, distributed biotech builds upon phenomena such as direct-to-consumer genetic testing and personalized genomics while providing a cultural and technological infrastructure for synthetic biology research. Early examples of this transformation towards commercialization include companies that design web-based platforms for distributed synthetic biology, inviting connected individuals to participate in drug development. Accelerators such as IndieBio, based in both the US and EU, fund "independent" biotech start-ups and help them position themselves on the market. The appearance of distributed biotech companies fosters further mobilization of new active contributors to biotech research. Yet, it also guarantees that these same groups can participate in the commercialization of products deriving from their contributions. For example, contributors to distributed drug development projects represent deregulated, outsourced laborers as well as potential consumers (Cooper and Waldby 2014, Lupton 2014). On the other hand, the emergence of distributed biotech start-ups is also part of an ongoing process of financial risk outsourcing in which pharmaceutical and biotech corporations harness value in the form of intellectual property or services created by new companies. While these start-up companies tend to require a relatively low initial capital, they also tend to absorb all risk of failure. This indicates that distributed biotechnology might abandon technical openness in favour of traditional intellectual property rights when adopted by market-based actors (Delfanti 2013).

Finally, some of the practices, equipment, and aesthetics stemming from DIYbio and other forms of biohacking are adopted and repurposed by educational institutions, such as universities and museums. Examples of the adoption of distributed biotech as a form of public communication includes a number of citizen laboratories opened by European universities, museum exhibitions on DIYbio, and collaborations between DIYbio community labs and schools to provide biotech-related student activities. Portable labs, such as Bento or The Amino, are commercialized as suitable for schools while community labs, such as New York's GenSpace, collaborate with science teachers to provide scientific education programs. Distributed biotechnology's emphasis on enabling citizens to directly carry out scientific research through hands-on approaches resonates with the increasingly common educational goal of outlining the processes that underpin biotech rather than its final results (Davies et al. 2015). Similarly, European groups have been involved in EU-funded research projects aimed at testing new forms of citizen participation under the umbrella of the European bioeconomy. Within these new frameworks, distributed biotech's goal of creating new and accessible spaces for biotechnological processes seems to dissipate the possibility of an independent, or even oppositional, biotech. This goal has become part of a standard narrative regarding the need for an increased consensus around biotech. In these cases, distributed biotech aims at creating "domesticated" publics through the interaction with transparent processes versus opaque results of biotechnological research.

Conclusions

Although it could be considered marginal if compared to major fields such as agrobiotech, pharmaceutical research or academic institutions, distributed biotechnology has been central to recent political transformations in the relationship between biology and society. Distributed biotech is comprised of different actors that exchange people, material and information. DIY biology groups, biohackerspaces, start-ups, incubators, as well as education and academic institutions all encompass this diverse field. Its current configuration is the historical and political product of a number of genealogies that combine actors of cultural and social diversity who have in common a dissatisfaction with the political economy of mainstream biotechnology. Distributed biotech is constructed through a complex entanglement of technical, political, and economic *openness*. Also, it fosters the idea that biotechnology can be a *personal* technology that individuals can appropriate for processes of consumption and entrepreneurship. Visions of a *distributed* biotechnology tend to present scientific progress as the result of the aggregation of free individual contributions. This is depicted as more efficient than centralized and bureaucratized research. Yet, while actors in distributed biotechnology communities or companies tend to construct their activities autonomously from mainstream biomedical research, processes of dependence and increased institutionalization are at play.

Practitioners, pundits, and scholars alike have explicitly linked the trajectory of biohacking, DIY and distributed biotechnology to that of personal computers in the 1970s. Under the influence of post-1968 countercultures, hackers first imagined that the computer could become personal: first, a community-based tool used for collective liberation, and later, an individual tool for mediated communication. This led to the commercialization of computers as personal technologies designed for mass consumption, breaking a monopoly held by corporations that viewed computers as tools for experts and institutions. This story is often told as an edifying narrative of democratization and economic success. And yet a more nuanced analysis reveals the contestations, ambivalences and tensions that characterized the rise of personal computers within a new ideological framework as well as corporate system. Similarly, distributed biotechnology aims at disrupting current monopolies within biological research. Yet while representing a change in the current balance of power in biotechnology, it contributes to the transformation of living matter into pliable, modifiable material that can be subject to industrial processes and further commodification. Furthermore, it presents the individual as the main subject that can produce a socially meaningful biology, either alone or through the aggregation of plural contributions into an emergent order. Nevertheless, the existence of groups that aim at reappropriating its processes and techniques for collective and autonomous purposes signals that, within this general framework, distributed biotech can be tweaked towards quite different ends. The political and technological evolution of distributed biotech is still open.

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