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Innovation regimes based on collaborative and global tinkering: Synthetic biology and nanotechnology in the hackerspaces

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ABSTRACT

Typically nanotechnology and synthetic biology are discussed in terms of novel life forms and materials created in laboratories, or by novel convergences of technologies (ICTs and biological protocols) and science paradigms (engineering and biology) they initiated. Equally inspiring is their ability to generate novel institutions and global communities around emergent sciences, which radicalize the forms of public engagement and ethical deliberation. We are starting to witness alternative (iGEM competitions) and almost underground R&D engagements with Synthetic Biology (DIYbio movement), which inspired the emerging bottom-up involvements in nanotechnologies in projects, such as the NanoSmanoLab in Slovenia. These bottom-up involvements use tinkering and design as models for both research and public engagement. They democratize science and initiate a type of grassroots "science diplomacy", supporting research in developing countries. We will discuss several recent examples, which demonstrate these novel networks ("Gene gun" project by Rüdiger Trojok from the Copenhagen based hackerspace, Labitat.dk, the "Bioluminescence Project" by Patrik D'haeseleer from Biocurious biotech hackerspace in Sunnyvale, CA, and the "Biodesign for the real world" project by members of the Hackteria.org). They all use design prototypes to enable collaborative and global tinkering, in which science and community are brought together in open biology laboratories and DIYbio hackerspaces, such as Hackteria.org or Biocurious. In these projects research protocols encompass broader innovative, social and ethical norms. Hackerspaces represent a unique opportunity for a more inclusive, experimental, and participatory policy that supports both public and global involvements in emergent scientific fields.

1. Introduction

Synthetic biology and nanotechnology are discussed in this paper in terms of their ability to "design" and generate original social and institutional support for their research and development. This is a direct expression of the innovative forms of ethical deliberation, which professional scientists, but also science amateurs and hackers embrace in their projects. Design and tinkering are essential for understanding these present practices operating on various scales, from the molecular to the social, which create unique interactions between social customs, ethical norms and scientific and technical protocols, which we discussed in our paper of NanoSmanoLab in Slovenia [1]. The amalgams of norms and protocols, which we are starting to witness around DIYbio and similar efforts, are basically prototypes enabling collaborative and global tinkering, which we will discuss with examples.

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The complex relation of synthetic biology and nanotechnology to both science (biotechnology, systems biology, bioengineering, genetic engineering) and society (ethical, legal, social, but also ontological and philosophical issues) can be summarized as an issue of convergence and hybridity, in which design plays a central role. The convergence between biology, computer science and ICTs enables synthetic biology to envision and "design" artificial and hybrid life displaying new traits not existing in nature. By applying design as well as engineering principles and techniques, synthetic biology synthesizes unique life forms, "LEGO" like bio-molecular components from which minimal and de novo organisms are produced, or configures and redesigns existing organisms [2]. Whether it is this bottom up (creating new living forms from basic components) or top down approach (so called "chassis", tweaking the genetic circuits and biochemical pathways of existing organisms), the art of designing life by "playing" or even "outwitting" both God and evolution incites unique normative and ethical responses. Synthetic biology goes often beyond the common, deontological or utilitarian calls for anticipatory policy, risk assessment, code of ethics or legal and ethical prudence. It incites rethinking of ethics and policy by supporting experiments with new ways science is performed and practiced in the present, institutional settings.

The converging and hybrid aspects of synthetic biology created their own ways of ethical inquiry and deliberation, which also enabled novel and more inclusive forms of public engagement in science. We will describe them as "experimental", "process" oriented and design inspired approaches, such as the well-known SynBERC "human practices" [3], DIYbio "codes of conduct" [4], but also less known "ethobricks" [5], and calls for "reflective equilibrium" models of justification [2,6], interdisciplinary and interactive "socioethical engagements" [7], "upstream engagements" [8,9]. All these attempts connect the research protocols in direct and novel ways with ethical norms and embody the ideal of "technologies of humility" and the "participatory turn of science studies" [10]. Their aim is to enable involvement of the various stakeholders and citizens in the whole research process from discovery to testing and policy making.

In this paper we discuss how these unique interactions between ethical (social) norms and scientific protocols, between values and facts, relate to design and tinkering and how they define present citizen science labs and hackerspaces. These convergences between social and ethical norms with scientific protocols (but also institutional customs, policy regulations, and laboratory facts), in projects such as DIYbio "codes of conduct" [11] or Paul Rabinow's "human practices" [3], all emphasize tinkering and design as models for both science and experimental forms of ethical deliberation and decision making. These spaces and projects engage both experts and lay people in science by exploring new ways of connecting scientific practices and techniques with society, culture and nature. Furthermore, they enable alternative global networks for knowledge creation and sharing, which support research in developing countries by performing the potential of open science approaches.

The experimental models of ethical deliberation and regulation are often dismissed out of hand. It is claimed they are just another attempt to formulate professional codes of ethics leading to "scientist-centric ethics" [8] or "scientific self-regulation" that presumably are symptoms of deregulation, demise of governance and commercial pressure [12]. This paper proposes a very different perspective on these unique interactions between codes, norms and protocols, emphasizing their experimental potential in deliberation and public participation in science and their potential to create new networks of knowledge transfer. We will argue that rather than simplifying complex ethical issues or playing safe, they create opportunities for various stakeholders to take part in both research and assessment and to experiment with science and society, knowledge and policy.

The unique interactions and convergences which we are starting to witness in the hackerspaces around the world between scientific practice and community building [13] lead to a more resilient, democratic and experimental model for acting and decision making. These experimental collectives probe various relations and scenarios around emergent technologies, and they connect policy and design under what will be described as cosmopolitics [14]. The cosmopolitical forms of public participation and deliberation, instead of separating powers and domains of knowledge and acting, policy and research, ethics and science, human agency and non-human matter, involve the various powers, actors and communities across scales and ontologies. We observed these experimental involvements of various actors and scales in several hackerspace projects, which we will describe at the end of the article, after we discuss the importance of design in the present convergences of protocols and norms. The novel innovation regimes are defined by collaborative and global tinkering, which brings together policy, science and design to create unique opportunities for public participation in science and in support of research in developing countries.

2. Designing, tinkering, making and deliberating

The pursuit of new forms of life and matter in synthetic biology goes hand in hand with the pursuit of testing and experimenting with new hybrid institutions and tentative forms of regulation. Design plays an important role in the various alternative engagements with both synthetic biology and nanotechnology. It summarizes well the unintentional, serendipitous and somehow opportunistic processes of both scientific discovery as well as ethical deliberation, and is also present in the definitions and descriptions of synthetic biology per se. For example, "SynBERC" (Synthetic Biology Engineering Research Center) and related "Keasling laboratory" websites explicitly define synthetic biology as a "design and construction of new biological entities" [15] and "redesign" of natural living systems, which will "simultaneously test our current understanding, and may become possible to implement engineered systems that are easier to study and interact with"[Ibid].

These definitions of synthetic biology as design basically state that theory merges with practice when concepts and tools go hand in hand with discovery and hypothesis testing. To redesign a system means to simultaneously test our understanding of it, to discover the new possibilities and limits of both knowledge and technology with which we can change it. The modular "parts", which drive this process and manage nature's complexity, are not simple "building blocks" of nature nor some tools for testing models, but complex socio-technical (and ethical) protocols for creating new systems and interactions not seen before [16]. These so called biological parts or biobricks (DNA sequences, which can be inserted into bacteria to perform certain functions) connect biology with engineering. They define knowledge as simultaneous creation of new organisms as well as experiments with social and ethical implications of such innovation.

Synthetic biology connects doing/knowing and theory/practice on every level. The biological "parts" are tools for designing and transforming nature and not simply objects or models of how nature works. They are products of design and standardization, but also they have an ability to create new organisms and increase nature's complexity ("design and construction of core components that can be modeled, understood, and tuned to meet specific performance criteria," [15]). They even recast nature "via a set of design rules that hide information and manage complexity, thereby enabling the engineering of many-component integrated biological systems" [Ibid]. This integration of scientific knowledge with design and tinkering is also expressed in one of the famous messages (attributed to Richard Feynman) encoded inside the first self-replicating synthetic bacteria (M. mycoides JCVI-syn1.0) by J Craig Venter Institute: "What I cannot build, I cannot understand" [8]. In this symbolic first inscription reflection is defined as intervention, and understanding is merging with doing. Design as a practice is central to synthetic biology and more important than agreements on a method or some demarcation of knowledge and regulation.

The importance of design in synthetic biology brings tinkering and making to the forefront. Creating tentative and constantly evolving knowledge has social and scientific values. The modular parts (biobricks, biological parts) both manage the complexity of the studied organisms (usually bacteria) and test our understanding of nature: "natural living systems have evolved to continue to exist, rather than being optimized for human understanding and intention. By thoughtfully redesigning natural living systems it is possible to simultaneously test our current understanding" [15]. They are also objects, which organize and incite open science approaches and novel organizations. Creating biological parts is reflective as much as it is a practical and organizational activity, during which we understand and change complex systems on multiple levels simultaneously.

Design and intervention occur not only in terms of material practices related to the biological and software techniques and substances, but also in terms of ethics, regulations and social institution supporting what Adrian Mackenzie in his "Design in synthetic biology" calls "forms of collaboration of standardization": "The notion of design as a meta-technique shows how synthetic biology assembles techniques and renders them available via practices of collaboration and standardization… Potentially, different ways of doing design imply different materialization of the living. Importantly, different ways of doing design entail different patterns of connection, relation and participation running across science, technology, institutions and cultures. Across each of these facets – rapid emergence, transformation in how biological work is done, multiple materializations of the living – design is writ large" [17].

This modularity in short allows us to design not only new life but also new assemblages of institutions and norms, which support collaboration in synthetic biology across professional and lay settings and which open the field to new actors: "Design is a meta-technique in that it organizes, groups, assembles and subsumes other techniques, practices, methods, protocols, knowledges, services, and infrastructures into specific arrangements, while at the same time, appearing to stand outside them. At the same time, because it brings new divisions of labor, a meta-technique also engenders, as we will see, processes of subjectification" [17].

The novel model of tinkering with life and matter has its counterpart in the modular and wiki style ethical deliberation also in Paul Rabinow's "human practices" and "techniques of living" (bios technika) [18]. Rabinow speaks explicitly of "experiments" where we have to invent ethical "parts" and tools in direct cooperation with the scientists, and thereby make humanities and social sciences not only relevant to synthetic biology, but also part of the joint "flourishing". The vision of such knowledge (synthetic biology) which will enhance us "ethically, politically, and ontologically" means transforming our ethical and social norms into modular parts enabling cooperation across various actors and disciplines.

Ethics and social norms are not merely historical facts that express our value systems as something that separates us from nature and defines our aspirations. They are also products of evolution and interaction with our environment, which is changing at the present time in terms of the possibilities synthetic biology presents. Rather than embracing some pre-given truths or practices, because of their obedience to the goddess Clio, we need to experiment and identify new aspirations: "Our experiment concerns the relations among and between knowledge, thought, and care, as well as the different forms and venues within which these relations might be brought together and assembled. Our commitment is anthropological, a combination of disciplined conceptual work and empirical inquiry. Our challenge is to produce knowledge in such a way that the work involved enhances us ethically, politically, and ontologically" [18].

3. Norms, protocols, prototypes or paradigms?

What is a prototype and how it relates to innovation and ethical deliberation? How does it help us understand these novel, design oriented forms of research and public engagement in synthetic biology and emergent innovation regimes? The concept of a prototype, which we use in this paper, derives from the epistemological discussions surrounding the forgotten concept of the paradigm in Giorgio

Agamben [22], which explains the present convergences between scientific protocols and ethical norms. Prototypes as a form of public engagement connect the material practices (facts, scientific protocols and tools) with the social sphere (norms, customs, values) in order to test some vision of future use and context. They probe how emergent technologies will interact with various other actors and fit various individual and collective needs [19–21].

The Hackerspaces and the DIYbio communities are testing grounds for biotechnological prototypes, where decision making involves the general and global public. They allow communities to organize themselves around certain molecules and/or technologies and to decide about which version of the future is the most worthwhile and deserving of further investment of effort, money and energy. They are amalgams of social and scientific practices with one main (cosmopolitical) function: to form unique equilibria between (newly emerging) actors and between theory and practice. They allow us to change and influence all sides and actors at the same time, and connect various norms and practices. They support iterative cycle of innovation that captures the ongoing activity of real people, unlike the mythology in the usual linear sketch that goes from discovery to translation (application), dissemination and adoption.

Prototypes basically integrate science experiments with political deliberation and make both of them part of an iterative design process that optimizes and tests these visions. They are tentative and temporal solutions that closely test the limits and possibilities, the adoption and dissemination of certain technologies. Prototypes connect design with ethics and even politics to offer utilitarian solutions to problems while protecting the almost deontological understanding of creativity and the value of deliberation as an open process, which involves increasing numbers of new actors and stakeholders. Prototypes connect the experimental method (scientific rigor and openness to discoveries) with the political idea of deliberation (involvement of different actors, negotiating different opinions and interests).

We have attributed a parallel and close connection between social and scientific innovation in synthetic biology to the hackerspace and DIYbio movements. This goes beyond the strictly limited alternative call for a "participatory turn" in science policy and it embraces the experimental ethical norms, which relate to the concept of "cosmopolitics" [14]. At its core cosmopolitics attributes equal value to all actors involved in a given historical situation and network, believing that – rather than by making strict normative rules and divisions – improvement comes through testing and openness to "paradigmatic shifts" not only in science but also in terms of social customs. This pragmatic turn insists on temporal and processual solutions in both social and scientific terms, which are enabled by prototypes.

How do prototypes connect technology, philosophy, ethics and social life and enable these experimental interactions? The prototype as a "novel" form of knowledge transfer and public participation, which we encounter in these emerging scientific fields, revives a much older idea of the role of iteration in knowledge creation, which the famous Italian philosopher Agamben discussed as an issue of the "paradigm" [22]. Analogy, exempla and paradigms according to Agamben form the hermeneutic understanding of meaning as a form of life, where reflecting and living basically merge. When we use "exampla" and when we search for analogy we create new relations between parts not previously connected, and we realize and experience a new unity. Prototypes just as examples are singularities, single cases that become models by virtue of repeatability and performance (we can add iteration). They are defined not by rules and laws or any generality (some code), but by performance, singularity and action – something that is as close to materiality and our senses as much as to the sphere of the intelligible and the social. Agamben is describing this as a type of attitude rather than methodology, which does not oppose reflection and action but rather brings them together into what he refers to as a "form of life" (forma vitae).

To explain the special power of the paradigm and the exemplum as tools of knowledge and organization, he uses the case of documents (regula) that regulate the monastic orders and forms of life. These regula, just like the rules probed and set up by the Hackerspaces today, are forms of prototypes connecting practices with norms and aspirations. The hackers test and describe on their wiki the managerial models how to run such spaces and projects dedicated to prototypes and enable others to follow. Regula in the past referred to the monk's way of life in a given monastery, which followed the founder's way of living (forma vitae), which in turn performs the life of Jesus. What defines an exemplum is this notion of constant performances rather than simple repetition, a performance emphasizing its own singularity rather than perfection: "at least until Saint Benedict, the rule does not indicate a general norm but the living community (koinos bios, cenobio) that results from an example and in which the life of each monk tends at the limit to become paradigmatic – that is, constitute itself as forma vitae… paradigm entails a movement that goes from singularity to singularity and, without ever leaving singularity, transforms every singular case into an exemplar of a general rule that can never be stated a priori" [22].

The emergent science and technology prototypes and institutions as "exempla" offer new ways of experiencing and understanding the connection between different actors and scales. They connect protocols with norms to create "exempla", which do not discover nor constitute any deeper layer of reality or law that governs our world and the ideal politicsvis-à-vis new scientific facts and emergent technologies. They are "probes" and precedents which serve as models for future actions. They simultaneously offer new insights into our present and past in terms of a special type of care that one takes of what exists and what might exist as described by Foucault in Agamben [22]. In this sense, they are expressions of the unique temporality of the "future anterior", of a time that performs its aleatory dimension rather than discovering its real meaning and goal. They liberate the future from the present and the present from the future by testing the different connections and paradoxes, rather than blindly following the rhetoric of innovation or some vision.

To think, design and regulate emergent technologies in our opinion means to experience such a "past in the future", to access the "moment of arising" and "transform the unrealized into realized and the realized into unrealized" [Ibid]. It means to "gain access to the present for the first time, beyond memory and forgetting or, rather, at the threshold of their indifference" [Ibid]. Hackerspaces and similar projects enable such policy based on the "future anterior" and paradigms by simultaneously connecting community building with scientific discoveries, social and scientific experiments, rather than trying to divide these processes into different domains and institutions. It is not a case of simple self-regulations with its ambiguities of power misuse, but more of a collaborative self-experimenting, in which responsibility, decision making and risk are tentatively negotiated rather than decided in advance.

With exempla, design prototypes and social/political probes in the form of iGEM, hackerspaces and similar experiments, we are not discovering something given in advance or reproducing existing and cherished institutions. To the contrary, we are generating and producing new connections between actors involved in our present historical situation and network. Paradigms as a way of thinking are neither forms of induction nor deduction. They are neither descriptive nor normative, but more like gestures, performances, which show the processes of their own assembling. They are models and experiences, which allow us to explore the limits of being human and being a community, but also to explore the new ways of life and the new possible configurations and assemblages between things, humans and institutions. Prototypes just like paradigms enable us to experience this simultaneity of possible futures. They are structured more like what is described by Foucault (in Agamben) as a form of freedom and dream: "The essential point of the dream is not so much that it resuscitates the past as that it announces the future. It foretells and announces the moment in which the patient will finally reveal to the analyst the secret (he or she) does not yet known, which is nevertheless the heaviest burden of (his or her) present… The dream anticipates the moment of freedom. It constitutes a harbinger of history, before being the compelled repetition of the traumatic past" [Ibid].

4. The new innovation regimes based of tinkering: hackerspaces

Synthetic biology with its insistence on design, which is neither pure research nor just an application, supports novel connections between various materials, life-forms, but also social structures in a type of a dream. The global communities and new institutions around synthetic biology, such as iGEM student competition or the OpenWetWare wiki project, demonstrate this close connection between social and scientific innovation. While these two initiatives support the ideals of open science and science education, they have only limited impact on public participation. These initiatives were the first steps, opening the laboratories for undergraduate students and supporting the idea of new models of knowledge production [23–25]. They tried to embody the radical calls for "socially robust knowledge" (Nowotny in Jasanoff [10]), "Mode 2 knowledge production" [26], "upstream involvement" [3] and "participatory turn" [10] behind many of the initiatives supporting public engagements with synthetic biology and nanotechnology. While they were able to experience the production of new scientific facts and technologies, the involvement of the general public remained purely discursive over the years. The citizens were never expected to form their own laboratories or to run experiments and collaborate with professional scientists.

This all changed with the emergence of the DIYbio movement in 2008 inspired by the open science models in synthetic biology. Various art and science centers, collectives and hackerspaces around the world started to involve not only students, but also citizen scientists and various enthusiasts and amateurs in their ad hoc laboratories, and to provide support for their projects. The experiments with synthetic biology or even nanotechnology happening in these alternative settings opened a much larger space for connecting science with various social, ethical and even esthetic issues, norms, but also actors. They enabled experiments not only with science, but as well with the social organization around research and the adoption of new technologies.

TheDIYbio grassroots projects present the true "participatory turn in science policy" and "upstream involvement" based on prototypes as forms of knowledge and practice (modeled after Agamben's paradigms and regula [22]). They connect facts and values, knowledge and institution, rather than play them one against the other. By creating citizen labs and wiki support for such projects they bring the "knowledgeable publics into the front-end of scientific and technological production" to "institutionalize polycentric, interactive, and multipartite processes of knowledge-making within institutions that have worked for decades at keeping expert knowledge away from the vagaries of populism and politics" [10].

Organizations and citizen labs, such as the global Hackteria.org network, Labitat and BiologiGaragen in Copenhagen, La Paillasse in Paris or MadLab in Manchester take the design orientation and tinkering spirit of synthetic biology a step further. They foster the intensive exchanges between various groups and interests, which Adrian Mackenzie described so well in the case of iGEM as "flexible and fluctuating flows of imitation, invention, and talent coordinated through exchanges of knowledge and information about materials, protocols, and techniques, as well as norms and values" [17]. The exchanges however involve a larger public that can experiment with facts, norms and values and test various ideas on how to connect the novel life forms with their everyday life and various esthetic modalities, but also normative issues and attitudes. Knowledge-production and innovation become simultaneously creative experiments with social structures. They are defined by extraordinary openness to the involvement of new actors and groups of people, and reduced emphasis on an isolated and hidden activity by a few experts that needs to be supervised, protected and regulated from the outside by third parties because of patents, laws, safety, policies etc.

5. Registry of biocurious parts and global tinkering with luciferase

A good example to discuss this design oriented innovation regimes around emergent sciences is the "Bioluminescence Project" organized by Patrik D'haeseleer in the first biotech hackerspace, Biocurious. This project summarizes well the "polycentric" knowledge-making processes, which involve new actors and amateurs in every stage of the research and implementation processes. The Biocurious uses wiki and workshops to involve people from various disciplines (art, architecture, agriculture), but also institutions and countries and invites them to cooperate, design and test prototypes related to emerging biotechnologies. Their prototypes also bring a unique interaction between various ideologies and positions in the debate on synthetic organisms, because they can support both, radical ideologies of permaculture sustainability, and movements advocating the use of synthetic biology in tackling food security issues.

The "Bioluminescence Project" started in 2011 is a good example of such prototype, which brings together norms and protocols in unique amalgams and enables collective experimentation with potential futures. It started as a typical citizen science initiative in which a group of enthusiasts works and meets regularly to study bioluminescent organisms and to support biodiversity. It soon developed into several synthetic biology and DIY open hardware initiatives, which involve a global public from New Zealand to Singapore and China, but also a wide variety of institutions and connections between the academia, businesses, nonprofit organizations in the Bay area, DARPA, and hackerspaces.

The citizen scientists from Biocurious were originally studying organisms, such as dinoflagellates, for which they built an algae growth chamber to test various conditions and optimize their growth. This interest in bioreactors and aquaponic systems connects many hackerspaces around the world, which are dealing with similar issues related to the sensors monitoring values such as pH, temperature, CO_2, and crowd sourcing information on the ideal conditions for the growth of various cultures and organisms. The aquaponic movement is especially strong in China because of food safety issues (David Li's project in Xin Che Jian, Shanghai hackerspace), but also in Singapore for reasons of food security (Stephan February from Hackerspace.sg who also started Aquaponics.sg).

These hackerspace bioreactors and aquaponic prototypes and projects often connect the interest in extreme green and permaculture strategies with interests in synthetic biology. They often start with an interest in sensors and crowd sourcing of data, but continue with questions about how to optimize the organisms and experiment with more advanced technologies while creating global networks of citizen scientists and testing cooperation with commercial and government organizations. While working on the photobioreactors in Biocurious the participants also developed an interest in bioluminescence bacteria, and decided to start learning and experimenting with biological parts in order to "hack a cell culture to produce bioluminescent light using luciferase" [27]. The original citizen science project of growing algae evolved rapidly into one of the first synthetic biology experiments run by amateur biologists. In the present (April 2013) they are also trying to gain DARPA funding for their open source photobioreactor, which can be used for space exploration, and they successfully crowd funded via Kickstarter a project on designing glowing plants as lamps. While working on this, they are also building an impressive global network of hackerspaces active in synthetic biology projects to which they want to offer their first ever registry of DNA parts designed and synthesized by amateur scientists.

The simple bioreactor prototype evolved into this large scale project while they were trying to substitute the typical Green Fluorescence Protein (GFP), used in the basic synthetic biology workshops performed in Biocurious, with the luciferase gene from the bioluminescent organisms. They decided to replicate and extend the results of the 2010 E. glowli iGEM project from Cambridge and rethink the use of synthetic organisms for designing lamps, urban architecture and various everyday products. This led to the crowd funding of "Glowing plants" idea over the Kickstarter.org platform, which will enable them to design DNA parts for sustainable natural lighting – plants (and in the future whole trees)which can glow. The luciferase will be the first DNA part and synthetic biology kit created and offered to the global community by a hackerspace (Biocurious), which also explores a different approach to synthesis and distribution of parts than the more famous Biobricks projects (connected to iGEM competitions). In cooperation with a startup, Cambrian Genomics, they plan to set up their own bioparts registry and database offered to anyone in the world to cheaply assemble such parts over a commercial hardware system for laser printing DNA.

While the cooperation with iGEM and ex iGEM team members is a very common strategy in DIYbio projects, the "Bioluminescence Project" is also exploring these new networks and relations. The work with algae and bacteria hacking inspired one member (Cameron Clarke) to look closer into various algae projects; he had explored the possibility of working in different places in the world where interesting organisms can be found and studied. This quest led him to Indonesia where he became acquainted with the local citizen science initiatives (organizations such as HONF and Lifepatch) that work closely with universities in Yogyakarta (UGM and Santa Dharma). At the meetings which took place in July 2012 an informal network of cooperation was envisioned through which several DIYbio enthusiasts and recent graduates from Canada and U.S. are already planning to visit Indonesia and work on various joint projects.

6. Global R&D around DIYbio

The "Bioluminescence Project" triggered an unexpected DIYbio and citizen science exchange network with its own version of grassroots "science diplomacy" connecting in the present U.S, Canada, New Zealand, China and Singapore. It is trying to support research in developing countries like Indonesia and recently also Nepal by making available less expensive laboratory protocols and infrastructure tested in Biocurious hackerspace or other citizen science labs. It also enables hackers from the U.S. and Canada to become engaged in challenging genetic engineering projects with local citizen scientists already active in various projects. The goal for the future is to build the first ever independent and freely available Bioparts Registry and database, which can support synthetic biology research in Indonesia and Nepal.

The July 2012 meeting only named a model of citizen science exchanges, which was already in place at least from 2009. The ongoing interaction between Indonesia, India and Europe was part of the Hackteria network initiative [28]. The joint workshops between Hackteria and the Indonesian citizen science laboratories (HONF, later Lifepatch) on fermentation projects and hacked webcams created a model of cooperation based on open source hardware tools for agriculture [13]. These networks of informal cooperation evolved over the years and in 2013 lead to an arranged meeting in Bangalore where artists, designers and hackers were hosted by the National Center for Biological Sciences and the Srishti School of Art, Design and Technology [24]. The interdisciplinary character of these workshops and the Hackteria network enable interpenetration between science education, design, and art with agriculture. What is even more important in the light of these recent negotiations between the DIYbio scene in the U.S. and Canada with Indonesia, the Hackteria initiative also created a model for open science networks. These exchanges support research in developing countries via open source hardware and open science models. The hackerspaces from Shanghai, Shenzhen, but also Kathmandu are joining these projects initiated by Biocurious and Hackteria. In the present they are discussing new DIYbio citizen science projects around sequencing aquaponic system organisms and building bioreactors.

This grassroots science diplomacy is radical because it ignores common geopolitical division and it also supports global south to south exchanges. Both India and Indonesia have a tradition of community oriented science, which is more responsive to citizens (especially in the rural communities) rather than big corporations. This is very important to the biohacker and DIYbio scene in search of community oriented science, which feels like a new movement in the "west" with various recent calls for a participatory role in science policy. The biohackers from the "west" are more like refugees in search of friendly and conducive environments in the global south, where they can join interdisciplinary projects, in which communities cooperate on the research rather than only "deliberate" and discuss over-politicized GM crops or a panoply of other contested issues. In this sense, grassroots science diplomacy is probing forms of exchanges and collaborations very different from the typical "development" projects, and it is much more open to indigenous and traditional knowledge [13]. The "Bioluminescence project" by Biocurious, not unlike many of the Hacteria.org projects, demonstrates how a simple work on one design prototypes (microscope, algae chamber etc.) can lead to a truly collaborative and global tinkering with innovative and radical ideas on how to connect science and the (global) community. The original innovation regimes around hackerspaces simply use prototypes to enable closer and innovative connections between science and community, and between research protocols and social visions, which create new models of cooperation, care and exchange.

7. Grassroots science diplomacy with gene guns

Another interesting prototype recently introduced in the European DIYbio scene (October 2012) has a great potential to reinforce these efforts and enable cheap forms of genetic engineering. This "agro-hacking" open source technology can improve the research possibilities in Indonesia and developing countries. The DIY "Gene gun" project by Rüdiger Trojok [Fig. 1.] from the Copenhagen based hackerspace Labitat.dk was presented in the autumn of 2012 in the local Medical Museion and it was one of the main items in their exhibition "Biohacking – Do it Yourself" (2013). This prototype created excitement in the DIYbio scene in Europe because it introduced a possibility of inserting DNA by force into an eukaryotic cells through a technology (cis-genetic modification) which is legal in the very strict anti-GMO EU climate. What this student and a famous biohacker tried to achieve was to open a discussion in the museum setting on what will happen when genetic manipulations becomes a kitchen practice with a cheap 30 USD tool: "The gene gun is a device to genetically transform plants. It was extensively used by Monsanto and similar companies in the 1990s to establish their power in the GM crop market. The usual price for a gene gun is around 15 000 USD. I made one from a whip dispenser for around 30 USD to show how this technology is in principle open to everyone. I just wanted to demonstrate the feasibility by doing that experiment in a museum. I also have to say that I haven't entirely tested its functionality and I'm still working on it, but I also hope someone else from the community will pick it up soon and contribute to it" [29].

What started in 2009 as a global agro-hacking informal network with Hackteria.org labs is evolving through such prototypes into an alternative model for R&D supporting

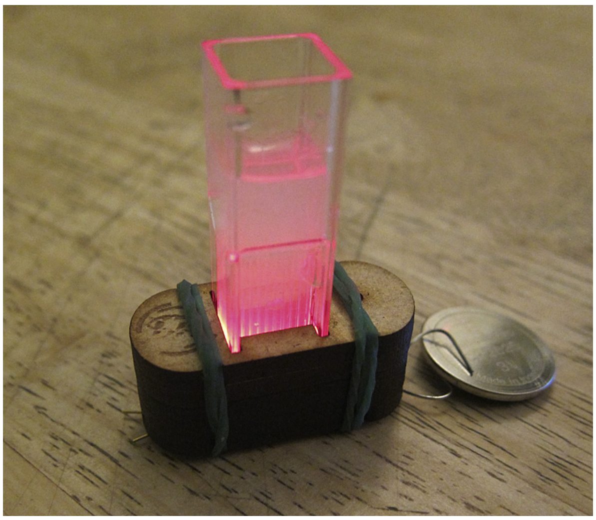

Fig. 1. Kafi-Schnapps Detektor: Optical Density and turbidity sensor based on Baby-Gnusbuino 2 USB board. Courtesy: Hackteria.org.

science in developing countries via Biocurious and various organizations in SE Asia (China, Nepal, Philippines, Indonesia, Singapore, India). The DIY gene-gun prototype and many Hackteria.org open source hardware projects are building an affordable infrastructure, which in the present serves education purposes, but it introduces a powerful vision of a global citizen science network supporting independent research. These projects and examples clearly document how tinkering with prototypes connects social and scientific projects and let us experiment with ideas never tried before. The hackerspace ethos in these projects enables groups and communities to reclaim technologies and introduce them in unexpected contexts, to rethink science as a community project. This closer connection between science and community, between research protocols and ethics, was brilliantly expressed in a recent interview with Cathal Garvey, a well-known biohacker from Ireland who points to agriculture as possibly the most important biohacking project for our future: “What of, for example, the opposition to genetically modified crops? In my experience, hatred of GMO crops more often than not begins to crumble when the possibility of true ownership emerges. Farmers, foodies and environmentalists alike find the idea of breedable, even personally genetically-modified crops far more palatable than the latest patented seed fare. And indeed, this is a burgeoning undercurrent in the DIY biotechnology movement; someday, we shall hack our own crops” [30].

The dream of hacking crops and similar global engagements around emergent technologies define not only the global DIYbio network, but also the emerging DIY nanotechnology labs organized by Hackteria.org network in Slovenia [31]. While the DIYbio engagements with biotechnologies use prototypes to connect community building with molecular interventions and to rethink the future collectives involving complex life forms, the DIY nano-engagements go step further. Science protocols are not only opportunities for novel innovation regimes and novel forms of social organization to appear, but a matter of interactions across various scales, which create their own cosmologies experimenting with some indigenous notions and animistic beliefs. The goal of citizen science in these nanotech labs is to rethink not only future society, but to create conditions for an almost cosmological reflection on how different scales relate to each other and how to interact and create a meaningful universe on such personal and everyday level.

8. Nanotech cosmologies and DIY microfluidics puppetry

In 2012 NanoŠmano labs (organized by Hackteria.org) used as one of their themes the “Life Seasons” chart (Pranoto Mongso), a farming calendar used in Java, Indonesia, to discuss issues of nanofarming. In a similar manner in which indigenous cultures structure their calendar to connect the macro-scale phenomena (climate, astronomy) to human and micro-scale phenomena (crop cycles, behavior of animals, even disease outbreaks), the nano-hackers were to connect their community garden to the nano-level particles and global geopolitical and climate phenomena. The temporary nano-lab in a community garden in the center of Ljubljana (Slovenia) was used as props for imagining the future of farming silver nanoparticles from mushrooms in urban environments. It also served as a familiar place, where humans, animals, plants, and various tools for sensing and manipulation on nanoscale were used to create interfaces for connecting the living and the artificial. These interfaces and methods were tested and the results documented and discussed over Facebook. Organisms that live in the garden (worms, butterflies, algae), together with various molecules, nanoparticles, but also visitors, resident artists and scientists performed an aesthetically driven explorations of the limits of our imagination and understanding of the newly emergent relations across various scales.

The annualNanoŠmano labs in Ljubljana are more like rituals, during which scientists and artists exchange their knowledge and goods to define a new “calendar” connecting the infinitely small and large. Participants are provoked to rethink the present cosmology and the relations across various scales of existence through playful appropriations of tools and forces, which operate on the molecular and nano level, such as laser micro-projectors, hacked DVD players into tweezers or other nanomanipulators, but also spherified liquids, microorganism, bioluminescence and similar phenomena. These playful appropriations create prototypes with an interesting trajectory of adoption and dissemination, which combines esthetic, artistic and social values along with scientific insights and reflections. They often start as educational and entertainment tools in the workshop, where the goal is to demystify science and probe new ideas. They develop into complex tools of cosmological and esthetic reflection to eventually become kits for supporting alternative R&D projects and involving the global bio- and nano-hacker community. In this later stage they embody the ideal of open science by becoming open source hardware lab equipment rather than a simple kit or a prototype.

The Hackteria DIY spectrophotometer [32] nicely summarizes this complex trajectory from a workshop prototype supporting unique art and science cooperation to an open source hardware project supporting water quality measurement and fermentation projects in the developing countries [33]. The various prototypes are often an opportunity to develop basic DIY techniques and build capacity in order to design new tools, which fit various contexts. For example, the DIY Micro Dispensing and Bio Printing [34] started as part of an exploration of DIY micro-Laser Cutters, and these simple experiments of casting PDMS on laser cut tape enabled a whole range of microfluidic devices [35]. These devices were originally used by Marc Dusseiller, one of the Hackteria.org founders, as educational tools in his university modules. As an educator, he experimented with a playful format of the so called biotic games [36] to explain the basis of how liquids behave on such micro level and how to create lab on chip technologies. Over the years these tools were also used to entrap and play with daphnia organisms and various molecules. In 2013 the plan is even to prepare a puppetry piece, in which daphnia will be manipulated as puppets in the micro-channels to perform on a special theater “stage”.

While the microfluidic devices remained artistic and creative explorations of how we interact on various scales, several prototypes developed into real tools, which can help research in developing countries. The simplified, but practical version of such prototype was recently disseminated over the Thingiverse platform (used for sharing open hardware projects) and serves as a kit for building optical density and turbidity sensors (Kafi-Schnapps Detektoe) [Fig. 2]. The “Lab-on-an-Arduino” Spectral Absorbance Shield (Optical Density Meter) [37] uses a simplified and cheap electronic board developed in Switzerland byAnyma.ch hackerspace founder, artist and hacker, Michael Egger from Fribourg. His 2 USD electronic board, Baby-Gnusbuino, simplifies the Arduino single-board microcontroller, which is used as a standard prototyping platform these days in most open hardware projects. Anyma's 2 USD board enables anyone to connect electronic components needed for laboratory equipment and to program them.

The 2 USD Baby-Gnusbuino was used in early 2013 by Indonesia citizen science lab Lifepatch in a workshop co-organized with Hackteria.org network, where it was transformed into even more efficient “Baby-MidiTurbidoGnusbuino” board used specifically for sensing turbidity in liquids and later tested in the Hackteria lab event in Bangalore [28]. The board connects LED with a light sensor, which measure show much light reaches the other end of a transparent container (a cuvette or Tic Tac containers) with various liquids. This simple device enables anyone to follow how many particles, inorganic or living, are in the water sample and measure their size. Measuring light absorbance and density of liquids is useful for assessing water quality or for measuring the density of microbial cultures, bacteria or yeast, which is important for culturing and brewing. Both of these functions play an important role in research projects based in developing countries [38]. This prototype summarizes the elaborate network and interaction between several academic institutions organized around the Biodesign.cc project, but also hackerspaces in Switzerland (Anyme, Swiss Mechatronic Art Society), independent R&D labs such GaudiLabs, and citizen labs in Switzerland, India and Indonesia (Hackteria, Lifepatch), which all influenced the design of the final kit from a playful prototype with Tic Tac containers.

Fig. 2. Rüdiger Trojok and his DIY gene gun. Courtesy: Malthe Borch from Biologigaragen.org.

While the original microfluidic experiments were artistic and playful reflections on the importance of the spheres in western cosmology, following their aesthetics and cultural references (such as the Hieronymus Bosch “Garden of earthly delight” [39]), the later experiments tested the possibilities of open hardware as a platform for building cheap lab equipment and supporting research in developing countries. The Hackteria projects enabled a global DIYbio network between EU and Asia, which is building infrastructure and enabling research in various contexts. The insistence on custom made Printed Circuit Boards and open hardware solutions developed between India, Indonesia, Switzerland and Slovenia, which are all part of the Hackteria network, defines them as tools of grassroots science diplomacy. The biohackers are starting to use the typical development and distribution platforms for open hardware projects (Kickstarter, Thingiverse) and cooperate with Shenzhen based open hardware markets, such as Seeedstudio.org, to offer their kits and solutions to a larger community, which will develop them further.

The unique processes and outcomes of these nano-hacking, DIYbio and open biology efforts show what true science participation and radical democratization of science can become a global movement. Communicating and deliberating, deciding on norms without being able to experiment and perform the protocols, will never create a participatory turn in science policy. Authentic participation comes only when science and community inspire each other and create unexpected ideas, networks and strategies in terms of prototypes, protocols, norms and visions for the future. These informal networks between artists, scientists, designers, hackers from various continents show how tinkering with technology, but also with social organization (of research, life etc.) or even cosmology, can serve as models of inquiry and prototyping of a truly global future.

9. Conclusion

The most innovative and important aspect of nanotechnology and synthetic biology today is the potential to create new, experimental models of research and development, new innovation regimes, which over the years created an alternative global network of hackerspaces and citizen labs. The division between lay and professional settings is blurred, offering a new perspective on the relation between laboratory and society, but also facts and values. The educational (iGEM) but also the global amateur science efforts (DIYbio, Hackteria.org, Biocurious, open biology citizen labs etc.) represent this convergence of ethical norms with scientific facts, grassroots innovation with self-regulation, “matters of concerns” (ethical, social, cultural, business) with “matters of facts” (research, innovation). These movements are organized around the ideas of crowd sourcing, open science, open hardware, peer production, but also tinkering and design, which define these new innovation regimes. Innovation and knowledge creation are becoming closer to the notions of prototype and paradigm rather than truth and method, enabling design to converge with policy making as well as philosophy. They represent the participatory models of science engagement while simultaneously probe the possibilities and limits of the abstruse notions of materiality, ontology and agency. Their goal is to integrate the emergent technologies into society by making us more aware of the different actors and stakes involved in synthetic biology and nanotechnology, but also of the various scales on which we operate in terms of thinking and doing, reflecting and creating, philosophizing and designing. These more socially involved and resilient innovation regimes are defined by interaction between politics (philosophy) and design and by experimental forms of connecting thinking and doing, reflecting and creating. They redefine the meaning of regulation from the more traditional model based on the separation of the executive from the normative powers (trias politica principle) to a more holistic model based on tentative rules constantly adapted to the changing situation of various new actors. Instead of dividing science and technology (as forms of executive power) from ethics (normative), the novel regimes revive what recent philosophy of science discusses as "paradigms" and "exempla" – neither institutions nor pure cognitive forms, neither an ideal form nor unique instances of knowledge, but cognitive and ontological probes into possible futures. Regulation of emergent technologies in these projects becomes more about conduct than policing; it is less about preventing and more about "cosmopolitical" experimenting. People are searching for models of how to share responsibility by integrating various legal, social and even esthetic aspects related to emergent technologies.

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