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From Bio-Ethics to Human Practice: Steps Toward Contemporary Equipment

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The various genome sequencing projects of the 1990s were significant in providing a first approximation of the core molecular information about the genome. They were no less significant for the ways in which they contributed to a reconfigured moral imagination and thereby to altering relations among and between biology, ethics, and anthropology. [1] From the outset, the genome projects and the bio-ethics programs affiliated with them traded on the notion that the genome contained the determinative essence of human identity. The run up to the announcement of the mapping and eventual sequencing of the human genome was replete with the rhetoric of revelation: in reading our DNA genomic scientists were uncovering the "blueprint" of life, the "holy grail" of biology. Of course, from the outset such rhetoric provoked contestation and rebuttal, but even then it was taken seriously and its proponents succeeded in setting the points of debate and communication. [2] As such a good deal of anthropological and ethical energy was spent working to imagine, understand, and critically evaluate the supposed capacities and threats introduced by massive genomic sequencing projects.

Ethics: Technology snd Equipment

In a major innovation, Federal funds – "the largest ethics project in human history" [3] as one actor put it – were devoted to the design and implementation of legal and cultural methods, procedures, and practices adequate to the challenges posed by the sequencing projects. Like the molecular technologies under consideration, these legal and cultural interventions were designed to achieve specified ends. [4] We call the specific mode of intervention and its standardization "equipment." In general, what is distinctive about equipment is that its task is to connect a set of truth claims, affects, and ethical orientations into a set of practices. These practices, which have taken different forms historically, are productive responses to changing conditions brought about by specific problems, events and general reconfigurations. The first National Commission, for example, was established, in part, as response to the abuse of research subjects of medical research. The Commission was mandated to develop practices by which research subjects could be protected. The form these practices took was guided by the following considerations: a truth claim (human beings are subjects whose autonomy must be respected), an affect (outrage at the abuse of such infamous research projects as the Tuskegee experiments), and an ethical orientation (human subjects must be protected from such abuse in future through the guarantee of their free and informed consent). With genomics more than the autonomy of subjects appeared to be at stake. For many, human nature as well as the integrity of nature more generally seemed threatened. Thus the sequencing projects contributed to a growing sense that bio-ethics urgently needed new means, designed to protect human beings from violations of their nature. Neither the affect of concern nor the desire to restrict genetic interventions was new, to be sure. What was new, however, was a growing sense that bio-ethics as it functioned in authorized spaces, such as government commissions, needed to be recalibrated to meet these new conditions. The means of that re-calibration are what we are calling "equipment."

Whereas the protection of research subjects involved the development of regulations "upstream" from research in the form of Institutional Review Boards and protocols for obtaining informed consent, human genomics appeared to require the design of a set of "downstream" practices. The objective of this equipment, this pragmatic mode of intervention and regulation, was to mitigate "social consequences" by restricting those directions and applications of research thought to pose a threat to the dignity of human beings. In the U.S., equipment of this kind began to be elaborated as part of the Human Genome Initiative ELSI project (ethical, legal, and social implications); it has been most thoroughly conceptualized and developed by the current President's Council on Bioethics. The architect and first chair of that Council, Prof. Leon Kass, proposed a truth claim, an affect, and an ethical orientation for the construction of such equipment: 1) bio-ethics matters precisely because what is at stake in biotechnology is humanization or dehumanization, that is to say, the essence of human being is on the line; 2) this state of affairs should inspire a measure of fear, and vigilance for in the face of scientific advance the "truly" human might be sacrificed; and 3) given the risk of dehumanization, the task of the ethicist is to discover what is truly valuable about human life in advance of any particular scientific endeavor and secure it against scientific excess.5

At the beginning of the twenty-first century, after two decades of genomics, it is now clear that the significance of biology for the formation of human life is more than molecular; today we are faced with new forms of the challenge of understanding living organisms and their milieus. New developments in the bio-sciences must be accompanied by the invention of new ethical and anthropological analysis and equipment. Focusing on a new synthetic biology engineering center with which we are associated, SynBERC, we argue that contemporary developments call for new forms of collaboration among ethics, anthropology, and biology. Collaboration is a form of engagement appropriate to the shared stakes of biological research and the broad assemblages within which such research is situated. It is animated by the recognition that ethicists, anthropologists, and biologists are working in a shared field of problems. Collaboration therefore requires more than observation and advice, more than submission to oversight. Collaboration requires a reflection on and adjustment of basic work habits. In this article we propose the initial steps in that direction.

Post Genomics: Human Practices

Under the leadership of Professor Kass, the President's Council was oriented by the view that bio-ethics must begin its work by identifying the "defining and worthy features of human life" so as to determine whether or not those features are put at risk by innovations bio-medical technology. Several characteristics of this orientation are noteworthy. First, these features of human life are universal and a-historical, that is, they obtain regardless of context or situation. Second, this means that they can be identified without reference to scientific developments. Third, as such, the defining features of human life serve as criteria by which particular scientific programs can be judged as threatening or not to "truly human" life.6

When the design of equipment starts with the supposition that science can only pose threats to the integrity of human nature, it is difficult for ethical understandings of anthropos to take into account the knowledge produced by contemporary molecular biology or anthropology. Ethics thereby would be positioned exterior to both biological and human sciences. Such positioning makes it more difficult to incorporate scientific knowledge in formulating the stakes and significance of contemporary human practices. Rather than excluding continuing scientific insight from our understanding of the human, it seems imperative to engage molecular biology and other sciences in order to learn what they can tell us about living beings. If one accepts this dialogic and contingent form of engagement, then scientific developments themselves prompt the question: are contemporary forms of ethical equipment required today? And what critical stance – in the sense of assessing legitimate limits and forms – is appropriate toward and within it?

Molecular biology demonstrated that DNA is shared by all forms of life and is a remarkably pliable molecule. This means on the one hand that if there are questions to be posed about qualitative distinctiveness of living beings – and there are – such questions must be posed at a different level than the molecular. On the other hand, it suggests that DNA can be manipulated without violating any laws of nature or deep ethical principles per se. Longer and longer DNA sequences are being constructed ever more efficiently and economically each year. Sequences are being inserted with increasingly precision and forethought into organisms; knowledge and know-how are accumulating about ways to make these organisms function predictably. What is at issue for the science, the ethics, and the anthropology is not the metaphysical purity of nature but the biological function of DNA sequences, the extent to which these sequences can be successfully redesigned, and ways in which these redesigns contribute to – or are nefarious to – well-being understood as a biological, anthropological and ethical question.

Living beings are complex in part because of their evolutionary history; they survived or perished under specific selective pressure in particular environments. Although the products of natural selection demonstrate fitness, this does not mean that this is the only way that the organism can function. Quite the contrary, while evolution certainly contains lessons about organic functionality, for contemporary biologists there is nothing sacred about the evolutionary paths followed to arrive at the functionality. Furthermore, the specific functions themselves are neither inviolable nor immutable. For biologists, there is no ontological or theological reason per se why specific functions – whatever their history – cannot be redesigned. Biologists indeed are making new things. And while this may not violate any sacrosanct ontology of nature, it does not mean that anything goes. It is precisely because we do not think that nature is by essence immutable that these practices and the objects they produce must be carefully examined. The effects of redesign do contribute to a problematization of things (ontology) that must be taken up, thought about, and engaged (ethics and anthropology).

In 2007, not only are genomes sequenced with regularity and a steady flow of genes inventoried and annotated but an array of other active biological parts and functions is being identified and catalogued. All of this science and technology proceed on the basis of a tacit faith in a principle of an economy of nature. That is to say that nature must consist in isolatable and describable units and functions. Many biological functions appear to be irreducibly complex in part because the capacities to analyze them, to break them down into parts, do not yet exist. One strategy to address this impasse is to invent the skills necessary to reconstruct those parts and make them function. It is that path – of analysis and synthesis – that is currently being grouped under the rubric "synthetic biology" and which concerns us here.

Today, in the early years of post-genomic science, the insufficiency of what has been called "the gene-myth" is now clearer. It has not been as frequently recognized, however, that the sufficiency of the standard bio-ethical models that arose along side the discourse of molecularization must itself be exposed to renewed questioning and reformulation. Questioning and reformulation does not mean jettisoning; much of existing bio-ethical equipment continues to serve a necessary function. It is simply prudent and consistent with our principles for those of us inventing new ethical forms based in phronesis to learn from the strengths and limits of previous practices. Limiting the intersection among ethics, science, and anthropology, however, to either upstream bureaucratic review or downstream impact regulation now appears poorly adjusted to the current situation of dynamic contingency and critical exploration in the biological and human sciences. In sum, loyalty to past practices can inhibit an ability to identify and analyze new challenges. We must take seriously the ways in which current transformations in scientific research modulate past problems as well as the equipment that had been invented to handle them.

Ethical equipment like that developed by the President's Council remains in an ambivalent relation to bio-scientific innovations. Strikingly absent from the development of this equipment is any attempt to incorporate the insights of contemporary science into definitions of what it means to be human. We hold that bio-ethics, as currently practiced in official settings, tends to undervalue the extent to which ethics and science can play a mutually formative role. More significant, it undervalues the extent to which science and ethics can collaboratively contribute to and constitute a "flourishing existence." As a place-holder, we note here that flourishing is a translation of a classical term (eudaemonia) and as such a range of other possible words could be used: thriving, the good life, happiness, fulfillment, felicity, abundance and the like.[7] Above all, eudaemonia should not be confused with technical optimization as we hold that our capacities are not already known and that we do not understand flourishing to be uncontrolled growth or the undirected maximization of existing capacities. Here we are merely insisting that the question of what constitutes a good life today, and the contribution of the bio-sciences to that form of life must be vigilantly posed and re-posed. Which norms are actually in play and how they function must be observed, chronicled, and evaluated in an on-going fashion. It is plausible that engaged observation stands a chance of contributing positively to emergent scientific formations. It is worth seeing if such observation can be effectively realized by conducting ethical inquiry in direct and ongoing collaboration with scientists, policy makers, and other stake holders. We are persuaded that within such collaborative structures: biology, ethics and anthropology can orient practice to the flourishing as both telos and mode of operation.

Synthetic Biology

The challenges of functional redesign presented by innovations in molecular biology are being addressed by a next generation of "post-genomic" projects. One such project is synthetic biology. Synthetic biology began as a visionary but minimally defined project:

> "Synthetic Biology is focused on the intentional design of artificial biological systems, rather than on the understanding of natural biology. It builds on our current understanding while simplifying some of the complex interactions characteristic of natural biology." "Those working to (i) design and build biological parts,

> devices and integrated biological systems, (ii) develop technologies that enable such work, and (iii) place the scientific and engineering research within its current and future social context."[8]

At the outset, the name was a basically a place-holder, or as some of its critics hold, a hoped for brand. Since its chief architects, however, understand synthetic biology as a process of modularization and standardization, it appears to us to be developing in and renovating a tradition nicely labeled the "Engineering Ideal in American Culture."[9] Unlike the visionaries of the sequencing projects, and their prophecies of the molecular as the "code of codes," synthetic biologists clearly have a feeling for the organism. [10] Synthetic biology aims at nothing less than the (eventual) regulation of living organisms in a precise and standardized fashion according to instrumental norms. There is a feeling of palpable excitement that biological engineering has the capacity to make better living things, although what that would mean beyond efficiency and specification opens up new horizons of inquiry and deliberation.

Today, the engineering project of building parts that either embody or produce specific biological functions and inserting them in living organisms is at the stage of moving from proposal to concept. The concept is being synergistically linked to an ever-expanding set of technologies and to increasingly sophisticated experimental systems. There is agreement within the synthetic biology community that a necessary if not sufficient initial step required to further this project is to conceive of, experiment with, organize, and reach broad consensus on, standardized measures and processes. The very qualities of living systems that make them interesting to engineering—that they are robust, complex, and malleable—also make them extremely difficult to work with. The extent to which these difficulties can be productively managed remains to be seen. In any case, at present hoped-for standards are recognized to be initially crude, and will certainly have to be reworked in an ongoing manner, but the important step is to begin to create them and to instill an awareness and sensitivity among practitioners as to their importance.

Synthetic biology arose once genome mapping became standard, once new abilities to synthesize DNA expanded, and once it became plausible to direct the functioning of cells. Its initial projects address a part of the global crisis in public health – malaria. At the same time, the first ethical concerns that it has to deal with arise from the risk of bio-terrorism (see below). The synthetic biology community is obliged to bring these heterogeneous elements into a common configuration. Put schematically, synthetic biology can be understood as arising from, and as a response to, new capacities, new demands, and new difficulties that oblige, in an urgent manner, contemporary ways of thinking and experimenting with vitality, health, and the functioning of living systems. Those investing in the development of synthetic biology expect that it will play a formative role in medicine, security, economics, and energy, and thereby contribute to human flourishing. Questions about what constitutes flourishing and the extent to which synthetic biology can indeed contribute to it are basic, and, more importantly, remain unanswered.

SYNBERC

In 2006 a group of researchers and engineers from an array of scientific disciplines proposed a five year project to achieve such standardization, with the aim thereby of rendering synthetic biology a full-fledged engineering discipline. Representing five major research universities—UC Berkeley, MIT, Harvard, UC San Francisco, and Prairie View A&M—the participants proposed to coordinate their research efforts through the development of a collaborative research center: the Synthetic Biology Engineering Research Center, or, SynBERC (www.synberc.org). SynBERC is highly unusual on a number of counts. In addition to its far reaching research and technology objectives, it represents an innovative assemblage of multiple scientific sub-disciplines, diverse forms of funding, complex institutional collaborations, an orientation to the near-future looking, intensive work with governmental and non-governmental agencies, focused legal innovation, imaginative use of media. More unusual still, from the start SynBERC has built in ethics as an integral and co-equal if distinctive component.

The SynBERC initiative is designed around four core thrusts: Parts, Devices, Chasses, and Human Practices. These thrusts, in turn, are designed to meet specified goals. Thrusts 1 through 3 link evolved systems and designed systems, with emphasis on organizing and refining elements of biology through design rules. Thrust 4 examines synthetic biology within a frame of human practices. It attends to the ways that synthetic biology may significantly inform human well-being through its contributions to medicine, security, energy, and the environment. 11 Critical examination of how synthetic biology will inform these domains constitutes a central concern of Thrust 4.

Several core synthetic biology projects were well under way prior to the organization of SynBERC. Two of these were particularly important for the development of Thrusts 1-3. The first is a project at Berkeley, led by SynBERC Director Jay Keasling. The project's goal is to take a molecule, artemesinin, that is found in the bark of a Chinese tree, and which is one of a small group of molecules that remain effective against malaria, and to engineer a system in which the molecule can be produced at a cost that is many times less than the extraction from the tree. This basic work has been accomplished – it is grown in yeast or e. coli through a re-engineering of the pathways of these common single celled organisms. So, synthetic biology, at least in this form, exists and it works. The major criticisms of the project come from those who have the legitimate concern that too much hope is being invested in a combination therapy based on a synthetic version of artemesinin that is likely to lead to its potential over-use and the consequent acceleration of resistance to it, with tragic results. That is a valid public health argument and those holding this position do not advocate eliminating this source, only thinking about consequences.

The partner chosen to take Keasling's work out of the lab and into those regions of the world where it most urgently needed, is another distinctive NGO, One World Health. The concept around which this NGO is organized is that hundreds of millions of dollars have been spent in research and development in the pharmaceutical and biotechnology industries that have yielded scientific insight, technical improvements, but often no commercially viable product. Their strategy has been to acquire (at the lowest possible cost) the intellectual property generated by this investment and work and to transfer it to countries like India where it can be adapted to local circumstances. The goal is to make available therapeutic advances that might be effective but are deemed to be not profitable enough for multi-national pharmaceutical companies. The quid pro quo is for those receiving the intellectual property not to compete in the same markets.

Although it is hard to imagine how one could argue that one should not encourage the development of new anti-malaria drugs in a world in which several hundred thousand people die each year from the parasite simply because the molecule to be used in therapy would be produced by re-engineering pathways in yeast or e. coli, this does not mean that no critical questioning should go on. But critical questioning requires knowledge and understanding. Hence, it is valid to argue that an over-abrupt use of a mono-therapy in a situation where the pathogen is highly adaptive is not a prudent strategy. And the synthetic biologists accept that criticism and are seeking to build the molecule so that poly-therapies that will reduce the likelihood of swift resistance can be built into the design (artificial, organic, natural, and emergent). Surely, changing the genome of yeast to produce artemesinin seems prudent and urgent, knowing full well that it is being designed to be introduced into the bodies of human beings and will thereby change both their internal milieu which already consists of multiple genomes (both contemporary and archaic) as well as the external milieu in which they live.

So, perhaps unique attention to the question of existing cultural understandings of nature and science at times can obscure other potentially more significant problems and questions. For example, what is perhaps most distinctive about this project is its funding and institutional setting. There is government research money, there is venture capital funding, there is university support, and the artemesinin project is funded in large part by the Bill and Melinda Gates Foundation. This foundation – with the gift of massive funding by financier Warren Buffet – has the largest endowment of any philanthropy in the world. It, like a few other new foundations – Google now has a for-profit foundation – are seeking to assemble health, science, policy, accountability, profit, delivery systems, management styles, scope, and timing in a distinctive fashion. Here is a very American assemblage with global reach. Its norms of productivity and accountability differ from those of the WHO or other such organizations in which national and international politics play such a distinctive part. This assemblage would certainly seem to be making a difference. And that diagnosis implies that we are obliged to think about its significance.

A second important project that was underway prior to SynBERC is located at MIT. It is devoted to building, or learning how to build, or to find out to what it extent it is possible to build, standardized biological parts, devices, and platforms. Its goal is to have a directory of such functional units available for order online – www.parts.mit.edu – and to make them available world wide on the basis of an open source license developed by a non-profit called Creative Commons. The core concept and initial work has taken place at MIT under the leadership of Professors Drew Endy and Tom Knight, integral members of the SynBERC initiative. One original organizational contribution, led by Randy Rettberg, has been to organize an international student competition, iGEM (genetically engineered machines) that has grown exponentially over the last three years to include the participation of over a hundred teams.[12]

Whereas one set of ethical and policy problems were raised by the Keasling project, the work at MIT poses a different order of challenge. Recent innovations in synthesis technology vastly expand the capacity to produce ever larger specified sequences of DNA more rapidly, at lower cost, and with greater accuracy. These innovations raise the stakes of the so-called "dual-use" problem (the idea that technologies can be used both constructively and destructively) expanding existing fields of danger and risk. The relation between technical innovation and the expansion of danger has long been identified in the world of genetic engineering. Previously, these trends have been framed as issues of safety, which can be addressed through technical solutions. To date a number of reports focusing on the governance of synthetic biology have adopted this framing.[13]

It has become clear, however, that not all challenges associated with synthetic biology can be dealt with through technical safeguards. For instance, changes associated with contemporary political environments, particularly new potential malicious users and uses (i.e. terrorists/terrorism), and increased access to know-how through the internet exceed technical questions of safety. Such challenges cannot be adequately addressed using existing models of nation-specific regulation. New political milieus produce qualitatively new problems that require qualitatively new solutions. In addition, we must confront the challenge of uncertainty characteristic of all scientific research. Although some risks are presently understood, we lack frameworks for confronting a range of new risks which fall outside of previous categories. Such frameworks would need to be characterized by vigilant observation, forward thinking, and adaptation.

Given these conditions, synthetic biology calls for a richer and more sustained inquiry and reflection then is possible in a study commission model of collaboration, wherein formal interaction ceases with publication of a report. To date, work in bio-ethics has largely consisted either of intensive, short term meetings aimed at producing guidelines or regulations, or standing committees whose purpose is limited to protocol review or rule enforcement. By contrast, we are committed to an approach that fosters ongoing collaboration among disciplines and perspectives from the outset. The principle goal of SynBERC's Human Practices thrust is to design such collaboration. This enterprise aims at giving form to real time reflection on the significance of research developments as they unfold and the environments within which research is unfolding. The aim of such collaborative reflection would be to identify challenges and opportunities in real time, and to redirect scientific, political, ethical, and economic practices in ways that would, hopefully, mitigate future problems and contribute to human flourishing.

Human Practices: Principles of Design

Within collaborative structures, practice can be oriented and re-oriented as it unfolds. This work is accomplished not through the prescription of moral codes, but through mutual reflection on the practices and relationships at work in scientific engagement and how these practices and relationships allow for the realization of specified ends. Straightforwardly: ethics and anthropology can be designed so as to help us pause, inquire into what is going on, and evaluate projects and strategies. The goal of the Human Practices Thrust is to design, develop and sustain this mode of collaboration. Given that goal, our wager is that the primary challenge for the Human Practices Thrust is the invention of diverse forms of equipment requisite for the task. If the scientific aims of synthetic biology can be summarized as the effort to make living things better and to make better living things, then the principle question that orients our efforts to invent contemporary ethical equipment is this: How should complex assemblages bringing together a broad range of diverse actors be ordered so as to make it more rather than less likely that flourishing will be enhanced?

We do not yet know what form contemporary equipment will take.[14] At this early stage of our work, however, three fundamental design principles appear worthy of elaboration and testing: emergence, flourishing, and remediation. In initial experimentation these design principles appear to be both pertinent and robust. They are pertinent in that they form part of the research strategies of the biologists and characterize the assemblage of relations within which the research is developing. Initial indications have shown them to be robust in closely related domains (e.g. bio-security). In these domains they have made visible unanticipated problems and interconnections, thereby opening up new and more appropriate modes of intervention and reflection. One of our initial aims is to test the robustness of these principles in synthetic biology.

Research in human practices is underdetermined. Past bio-ethical practices, often operated as though the most significant challenges and problems could be known in advance of the scientific work with which these challenges and problems were to be associated. Our hypothesis is that such practices are not sufficient for characterizing the contemporary assemblage within which synthetic biology is embedded. This assemblage is a contemporary one: it is composed of both old and new elements and their interactions.15 While some of these elements are familiar, the specific form of the assemblage itself, and the effects of this form, can only be known as it emerges. We understand emergence to refer to a state in which multiple elements combine to produce an assemblage, whose significance cannot be reduced to prior elements and relations. As such, the problems and their solutions associated with synthetic biology cannot be identified and addressed until they unfold. Questions concerning what it means to make life different, what it means to make living beings better, and what metrics and practices are appropriate to these tasks can best be addressed in real time as challenges arise and breakdowns happen. The knowledge needed to move toward the desired near-future will be developed in a space of relative uncertainty and contingency. Adopting a vigilant disposition that is attentive to a mode of emergence is at the core of our work. In sum our equipment must be designed such that it generates knowledge appropriate to states of emergence.

In the 1990s bio-ethical equipment was designed to protect human dignity, understood as a primordial and vulnerable quality. Hence its protocols and principles were limited to establishing and enforcing moral bright lines indicating which areas of scientific research were forbidden. A different orientation, one that follows within a long tradition but seeks to transform it, takes ethics to be principally concerned with the care of others, the world, things, and ourselves. Such care is pursued through practices, relationships, and experiences that contribute to and constitute a flourishing existence (eudaemonia). Understood most broadly, flourishing ranges over physical and spiritual well-being, courage, dignity, friendship, and justice although the meaning of each of these terms must be re-worked and re-thought according to contemporary conditions. The question of what constitutes a flourishing existence, and the place of science in that form of life, how it contributes to or disrupts it, must be constantly posed and re-posed in such a form that its realization becomes more rather than less likely. In sum the equipment we are developing must be oriented to cultivating forms of care of others, the world, things, and of ourselves in such a way that flourishing becomes the mode and the telos of both scientific and ethical practice.

The third design challenge is to develop equipment that operates in a mode of remediation. The term remediation has two relevant facets. First, it means to remedy, to make something better. Second, remediation entails a change of medium. Together, these two facets provide the specification of a specific mode of equipment. When synthetic biology is confronted by difficulties (conceptual breakdowns, unfamiliarity, technical blockages, and the like), ethical practice must be able to render these difficulties in the form of coherent problems that can be reflected on and attended to. That is to say, ethical practice remediates difficulties such that a range of possible solutions become available. In sum, our challenge is to design contemporary equipment that will operate in a mode of remediation. This equipment must be calibrated to knowledge of that which is emergent, and enable practices of care which lead to flourishing.

We do not presume to know in advance of its actual scientific work how synthetic biology will inform human life. We are persuaded, however, that ethical observation and anthropological analysis is capable of contributing positively to the overall formation of synthetic biology. We think that our contribution can only be effectively realized if this work is conducted in direct collaboration with scientists, policy makers, and other stake holders. Standard approaches have sought to anticipate how new scientific developments will impact "society," and "nature" positioning themselves external to, and "downstream" of, the scientific work per se. The value of collaboration is that it constitutes a synergistic and recursive structure within which significant challenges, problems, and achievements are more likely to be clearly formulated, successfully evaluated, and changed. Following our design principles, our goal is to invent new sets of contemporary equipment, put it into practice, and remediate things as they unfold.

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NOTES

[1] Thanks to NSF # for funding. To Drew Endy and Jay Keasling. And to all the readers and ARC members.

[2] This rhetoric still circulates. A summary statement of the significance of the Human Genome Project found on the U.S. National Genome Research Institute website reads, "Completed in April 2003, the HGP gave us the ability to, for the first time, to read nature's complete genetic blueprint for building a human being." http://www.genome.gov/10001772

[3] Eric Juengst.

[4] On the concept equipment: Michel Foucault 1977-8 and 1981-2 courses. Paul Rabinow French Modern: Norms and Forms of Modern Equipment, Chicago: University of Chicago Press, 1989. For more on the technical meaning of "equipment" in ethics, see the Anthropology of the Contemporary Research Collaboratory at www.anthropos-lab.net.

[5] See http://www.bioethics.gov/transcripts/jan02/jan17session1.html

[6] Find at www.bioethics.gov

[7] We will address these issues at more length in another article.

[8] http://conference.syntheticbiology.org:

[9] The phrase is from Pauly, P. 1987. *Controlling Life. Jacques Loeb and the Engineering Ideal in Biology*. Oxford / New York: Oxford University Press.

[10] Hood and Kevles, *The Code of Codes*, Keller, *A Feel for the Organism*

[11] For more details see www.synberc.org. This article only treats the efforts of the fundamental modules of Thrust 4.

[12] See http://parts2.mit.edu/wiki/index.php/Jamboree

[13] Sloan report, Fink report.

[14] For more on the technical meaning of "equipment" in ethics, see the Anthropology of the Contemporary Research Collaboratory at www.anthropos-lab.net.

[15] For more on this technical use of the term "contemporary" see ARC.