TOWARD A PHILOSOPHY OF BIOTECHNOLOGY: AN ESSAY

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ABSTRACT. In this paper, I try to sketch out the beginnings of a philosophy of biotechnology. First, I summarize efforts to date on the topic. I then turn to some other beginnings within the philosophy of technology, to which contributions I hope to make some additions. In order address an engineering philosophy of biotechnology, one must take into account the epistemological character of engineering sciences as both practical and descriptive. Thus, biotechnology is not simply applied biology. It is a highly complex ensemble of relationships with genetics and biological sciences, constrain by items such as management, the state of the art at any given time, and public and political inputs. Biotechnology may be the wave of the twenty-first century, but if the twentieth century has taught us anything, scientific and technological developments are fraught with social consequences, and in a democratic society, public discussion of such issues is indeed welcome.

KEY WORDS. Biotechnology, technology, engineering, epistemology, genetics, applied science, social consequences of technology, reductionism, public debate, state of the art.

INTRODUCTION

It is not only the completion of the ambitious Human Genome Project that makes biotechnology in all its facets a hot topic. Everyone who reads popular science at any level knows something about *Dolly* the cloned sheep; they might even know that *Dolly* have died and has been duly enshrined in her native Scotland. Many also know about controversies over genetically-altered foods, the so-called "frankenfoods" and resistance to their introduction into some countries, especially in Europe. And the story goes on, sometimes with praise for biotechnology or bioengineering as the only hope for starving people in underdeveloped countries, but more often with blame for crossing a threshold that humans (scientists) ought not pass (or something similar) almost always in a tone of high dudgeon.

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In this paper I try to sketch out the beginnings of a philosophy of biotechnology. First I summarize efforts to date on the topic. There are a number of preliminary efforts, from a variety of what I consider limited perspectives. I then turn to some other beginnings within the philosophy of technology, to which contributions I hope to make some additions.

A. PHILOSOPHICAL WORK TO DATE

Philosophers, historically, have attempted to tone down heated discourse of the kind that bedevils public discourse on biotechnology; we philosophers try to introduce the voice of reason. To some extent that has been true already, and before anything else here I will do a brief survey of the literature that is currently available under a philosophy of biotechnology heading. However, to be truthful, there has not been as much work done on the topic as one might expect. Here is a summary of some of what has been done.

A.1. ETHICS

As one should expect, the bulk of the literature so far falls within the range of ethical concerns, broadly construed in line with the shrill complaints about genetic engineering and other aspects of biotechnology. One of the earliest attempts by a philosopher—an analytical philosopher in this case—to be balanced in his approach was that of Jonathan Glover, in his *What Sort of People Should There Be?* (1984); there Glover gives a cautious green light to some sorts of genetic engineering.

At about the same time, a Heideggerian, Wolfgang Schirmacher (1987) offered his reflections on the early debate in Germany. Schirmacher's endorsement was even more positive, arguing that we have a responsibility to use genetic manipulations to improve human behavior, so often less than moral up to now.

In our library at the University of Delaware, moreover, I have found at least four books with genethics or a variant in their titles: David Heyd, *Genethics: Moral Issues in the Creation of People* (1992); Kurt Bayertz, *GenEthics: Technological Intervention in Human Reproduction as a Philosophical Problem* (1994), reflects the same German debates as Schirmacher; David T. Suzuki, *Genethics: The Clash between the New Genetics and Human Values* (1989), more critical; and David T. Suzuki, *Genethics: The Ethics of Creating Life* (1988).

Nor does this exhaust the list. There are at least two collections with similar titles: Justine Burley and John Harris, *A Companion to Genethics* (2002), contributions mostly by philosophers; and M. Khoury, W. Burke, and E. Thomson, eds., *Genetics and Public Health in the 21st Century: Using Genetic Information to Improve Health and Prevent Disease* (2000), mostly non-philosophers and mostly optimistic.

In addition (and finally, because my intent is not to be exhaustive), there are two textbooks on related subjects: Michael Boylan and Kevin E. Brown, *Genetic Engineering: Science and Ethics on the New Frontier* (2001); and Michael C. Brannigan, *Ethical Issues in Human Cloning: Cross-Disciplinary Perspectives* (2001), which includes an interesting range of perspectives from religious ethicists.

A.2. POLITICS

Many things have been written about the politics of various aspects of genetics, including the exporting of genetically modified foods and seeds to various countries. But one philosopher has had the field all to himself in providing balanced, judicious assessments of all aspects of biotechnology. That philosopher is Sheldon Krimsky; see the following books: *Genetic Alchemy: The Social History of the Recombinant DNA Controversy* (1982); *Biotechnics and Society: The Rise of Industrial Genetics* (1991); and *Agricultural Biotechnology and the Environment: Science, Policy, and Social Issues* (1996).

A.3. PHILOSOPHY OF BIOLOGICAL SCIENCE

For the most part, philosophers of biology, though that subfield is flourishing, have had little to say about biotechnology. On the other hand, they have had much to say about genetics, where one big issue has been whether genetic explanations are (wrongly) reductionistic.

The basic science (accessible to an intelligent lay reader) can be found in Michel Morange, *The Misunderstood Gene* (2001). Morange is not a philosopher but a biologist and historian of science; however, his treatment of genetics is judicious and balanced enough to satisfy any philosopher. He also, conveniently, has authored a *History of Molecular Biology* (1998).

The basic reductionist text is Richard Dawkins's *The Selfish Gene* (1989). Kim Sterelny, *Dawkins vs. Gould* (2001), summarizes one controversy. And Richard Lewontin, in *It Aint Necessarily So: The Dream of the Human Genome and Other Illusions* (2000a), and *The Triple Helix: Gene, Organism, and Environment* (2000b), provides the best-known anti-reductionist counterpoint.

Many traditional philosophers of science, including philosophers of biology, are critical of social-constructivist interpretations of the sciences, including the biomedical sciences. The major social constructivist who has worked closely with biological research communities and provided detailed quasi-anthropological accounts of what goes on there is Karin Knorr-Cetina, beginning with her *The Manufacture of Knowledge* (1981), but continuing in such studies as Image dissection in natural scientific inquiry (1990, with Klaus Amann). Knorr-Cetina's work neither takes sides in the reductionism controversy nor deals directly with biotechnology, but it could support the claim that much of what passes for pure science in biology is closely akin to goal-directed biotechnology as found in Krimsky's industrial genetics labs (above).

B. PHILOSOPHY OF BIOTECHNOLOGY PROPER?

At last we come to the main point of this project. One of the reasons why traditional philosophers of biology have little to say about biotechnology beyond the issue of genetic reductionism is that they often buy into (at least implicitly) the notion of biotechnology as simply applied biology.

B.1. BIOTECHNOLOGY AS APPLIED MEDICAL SCIENCE

The philosopher who has identified technology (in general) with applied science is Mario Bunge, and he has spelled out this approach to biotechnology explicitly in his magnum opus, *Treatise on Basic Philosophy* (multivolume, each volume with a different date, beginning in 1983; the material on biotechnology is in volume 7, 1985, pp. 246 ff.). Bunge begins: "This section deals with biotechnology" (p. 246), and it becomes obvious very quickly what Bunge's approach is, as he says next, "Iatrophilosophy, or the philosophy of medicine..." where he identifies philosophy of biotechnology with philosophy of medicine. Unfortunately, according to Bunge, "not much serious iatrophilosophy has been published yet, so there is much that analytically oriented philosophers could do to prepare the terrain" (p. 246).

Bunge continues: "Medicine [recently tapping biology in general and molecular biology in particular]... is now on the right track, though it has a long way to go before attaining the rigor and effectiveness of engineering" (p. 246).

For Bunge, "Therapeutics [is] a branch of biotechnology" (p. 248). And he provides what for him is a telling example: "Once... a [biochemical] mechanism [of a pathogen] has been unveiled, the technical problem of designing drugs inhibiting the pathogen can be posed in precise terms" (p. 249). So medicine can become a science, and medical cures are straightforward engineering applications of that science. If this seems too narrow and deterministic, Bunge admits that, "Over the past decades, medicine has gradually... adopted the systemic model of man as a biopsychosocial entity" (p. 249) so the range of medical sciences to be applied in bioengineering and biotechnology has been broadened considerably. But whatever the branch of medical science and therapeutics as straightforward bioengineering, the model is the same: science applied equals engineering or technology. For more detail, see Martin Mahner (with Bunge), in *Foundations of Biophilosophy* (1997).

B.2. CRITICS OF THE APPLICATION MODEL

Historians of science and technology, for more than twenty years, have attacked the notion that technology (or engineering) is simply applied science; see, for example, Edwin Layton, *A Historical Definition of Engineering* (1991, where Layton summarizes his own previous work and that of other historians). But I am not aware that any of them have challenged Bunge on biotechnology.

Philosophers have similarly challenged the applied science model. For example, in the same volume in which Layton's historical critique appears, philosopher Steven Goldman (1991) argues that the nature of engineering has been obscured by both scientists and engineers (along with managers and the public), who think along the lines laid out by Bunge. By cloaking their work in the mantle of praise for science, nearly always adding for the public good, engineers and their defenders, according to Goldman, are able effectively to mask the social determinants of technological action that actually drive modern engineering at every level, including the level of what counts as engineering knowledge. Using example after example of how engineering decision makers almost never pursue the technical best, deferring instead to managerial decisions about what to pursue and how far, Goldman concludes:

> Engineering thus poses a new set of epistemological problems deriving from a rationality that is different from that of science. The rationality of engineering involves volition, is necessarily uncertain, transient and non-unique, and is explicitly valuational and arbitrary. Engineering also poses a distinctive set of metaphysical problems. The judgment that engineering solutions work is a social judgment, so that sociological factors must be brought directly into engineering epistemology and ontology (Goldman 1991, p. 140).

In my long experience working with engineers, industrial chemists, and others in science-based industry, this is not going to come as any surprise. On the other hand, these captive experts tend to see nothing wrong with the applied science model. Goldman attributes this to a kind of cultural blindness: The purported value neutrality of the technical is an ideologically motivated stratagem. (Goldman says engineers voluntarily go along with their managers, with whom, on this point at least, they share the ideology.) It serves, Goldman goes on, to insulate from criticism the social factors determining technological action (p. 141).

Goldman's conclusion is controversial, but it seems to me that both critics and defenders of engineering agree on the captivity of engineering practice. Defenders seem to claim that engineering, freed of its constraints, could be more objective, which is clearly Bunge's hope. Critics like Goldman say, instead, that we have to judge engineering, even engineering's epistemology or knowledge claims not by what it might be, but as it is in the real world.

None of Goldman's examples has anything to do with biotechnology, but I have a really good example that does. The University of Delaware has recently joined with an industrial joint venture to create the Delaware Biotechnology Institute. About this, the president of the University says that, "This century is going to be the century of biology. We are on the verge of something very, very important in the whole history of mankind." For purposes of supporting DBI, the State of Delaware defines biotechnology ventures as including: "Any company that makes medical devices, analytical equipment, laboratory service providers, the entire pharmaceutical industry and businesses that focus on crop protection and the development of bio-based materials." And according to Delaware's governor, all of this represents the next evolution of Delaware's science-based growth. Finally, the director of DBI says "it seeks academic researchers who are comfortable in an institute that promotes commercial scientific applications." (All these quotes come from an article by reporter Michael Sigman, Bio-Feedback: "Biotechnology is the wave of the future, and Delaware is riding the crest," *Delaware Today*, November 2002, pp. 73 ff.)

It would be hard to imagine a better description of captive biotechnology, similar to Goldman's captive engineering.

B.3. AN ENGINEER'S PHILOSOPHY

Because I think engineering is a key component of any adequate philosophy of technology (see Durbin, 1991, introduction), I pause for a moment to consider the philosophizing of an engineer, Billy Vaughn Koen (1985, 1991, 2003), who believes both that engineering has been almost totally ignored by philosophers and that he has captured the essentials of the engineering method. It also happens that, in his latest book (2003) which ambitiously turns his engineering method into the universal method of human problem solving, Koen also includes a brief comment on the current state of bioengineering.

The essence of the engineering method that Koen thinks he has discovered can be summarized briefly (too briefly?) under two headings: heuristics, and *sota* or state of the art. Koen concludes: "My Rule of engineering is in every instance to choose the [always fallible] heuristic from what my personal *sota* takes to be the engineering *sota* at the time I am required to choose" (Koen, 1991, p. 57). And: "If... all engineers in all cultures and all ages are considered, the overlap [among their *sotas*] would contain those heuristics absolutely essential to define a person as an engineer" (p. 58).

Koen has little use for definitions like that of Bunge, that engineering is applied science, though he readily admits that engineers *sotas* do include scientific knowledge. Nor does Koen agree wholeheartedly with Goldman's anti-Bunge captive engineering view, though he does emphasize that the state of the art in any engineering project clearly must include managerial and other non-engineers constraints (including public and political input). What Koen wants us to see is that good (he would even say the best) engineering practice always contains the fallibility of heuristics (he thinks unlike science), but it is also always bound by best practices of the time, the *sota* or state of the art. I mentioned that Koen is willing to go far out on a weak branch to generalize:

> The responsibility of each human as engineer [is] clear. Everyone in society should develop, learn, discover, create, and invent the most effective and beneficial heuristics. In the end, the engineering method is related in fundamental ways to human problem solving at its best (Koen 1991, p. 59).

And Koen's latest book, *Discussion of the Method* (2003), attempts to turn this generalization into the universal method of human problem solving, following in a long line of philosophers (and others) who have attempted to discover such a universal method. All of that, however, is far from my focus here.

What is relevant is Koen's few comments (2003, p. 249) that apply his universal method to an assessment of the state of the art today in bioengineering:

> Both behavioral and genetic engineers recognize that they want change in a highly complex, unknown system and, not surprisingly, instinctively appropriate the title engineer. Saying you are an engineer, however, doesn't necessarily mean that you are a very good one (Koen, 2003, p. 249).

What is the source of Koen's skepticism with respect to genetic (and behavioral) engineering? He goes on:

> The present state of the art of both the behavioral and genetic engineer contains the appropriate heuristics for behavioral modification, but few of the heuristics of engineering... Neither has the slightest notion of the importance of making small changes in the *sota*, attacking the weak link, or allowing a chance to retreat (p. 249).

This is a serious indictment of genetic (and behavioral) engineering, as currently practiced, and here it comes from an engineer/philosopher, not from one of the public critics of bioengineering and biotechnology.

B.4. BIOENGINEERING SCIENCES AND BIOTECHNOLOGY

A third step toward a philosophy of biotechnology was suggested to me by one of my doctoral students, now a postdoctoral colleague. Ana Cuevas

Badallo, in her ambitious doctoral thesis (2000), discussed the role of the engineering sciences in a new philosophy of technology that would be more adequate than any offered so far. After listing more than a dozen engineering sciences, classical and modern, she chose to focus on the most traditional, the so-called "strength of materials." But her basic list (Cuevas Badallo, 2000, pp. 79-80), a very standard list in engineering education, extended from strength of materials to aeronautic engineering, systems of control, management as a part of engineering, and our focus here bioengineering and genetic engineering. She ends her thesis this way:

> Here I have analyzed only one theory among the engineering sciences, so the future is open to see if the proposed characterization is correct in relation to other cases, a task beyond our present scope. The conceptual framework presented here needs to be refined through studies of other engineering sciences and their relationships to other natural sciences, to mathematical sciences, and even to the social sciences (p. 372; my translation).

In the remainder of this paper, I attempt, among other things, to see whether Cuevas Badallo's framework would hold up in a philosophy of biotechnology that might be elaborated along her lines.

Cuevas Badallo's argument is simultaneously simple and complex. The simplicity is to be found in a schema she borrows from Miguel Angel Quintanilla (1996; in this respect, he does not depart far from Bunge's line of argumentation). According to Quintanilla, knowledge of any kind must fall into one of four categories: tacit practical, explicit practical, tacit descriptive, or explicit descriptive. (The original Spanish has *operacional* and *representacional*, and Bunge sometimes uses English transliterations of those terms; but standard lingo in English-language philosophy of science which, recall, almost never talks about the engineering sciences is closer to practical and descriptive, even when it implicitly accepts Bunge's applied science model.)

The complexity comes in a careful analysis of strength of materials as a set of engineering sciences going all the way back to Galileo at the beginning of modern science. From the beginning, engineering sciences (long before engineering was recognized as a separate cognitive enterprise) for purposes of designing fortifications, bridges, and similar structures had to adapt the laws of mechanics to suit practical purposes: The engineering sciences [here, strength of materials] are permitted certain simplifications and abstractions which, from the point of view of the natural sciences [here, the laws of mechanics], would be unacceptable.

Cuevas Badallo draws the following conclusions about the epistemological character of such engineering sciences as the (formulas of) strength of materials: they are simultaneously both practical, as they are related to specific engineering goals, and descriptive, inasmuch as strength of materials equations share with the laws of mechanics (from which they cannot be derived by any process of application) the character of being laws of nature or descriptions of the world (here the practical world) as it is. (She acknowledges Goldman's captive knowledge formulation, but she is attempting to characterize more precisely what he is getting at, using specific examples of theoretical-practical formulas used everyday, successfully, by engineers.)

Are there engineering sciences (not unlike cookbook formulas, but at a higher theoretical level) in biotechnology? Cuevas Badallo does not say, but her conclusion (above) hints that her thesis might be applicable in that area of engineering every bit as much as in structural engineering.

To support this hint, I refer to four crucial discoveries in genetic engineering: cutting DNA strands using restriction enzymes; recombining them; proliferation of useful genetic materials through polymerase chain reactions; and so-called knockout or gene inactivation studies for the purpose of determining gene activities in a precise way. All of these discoveries are complex and have led to what outsiders might view as cookbook formulas somewhat parallel to strength of materials equations, but it is interesting that people have been awarded major science prizes for their discovery, however inseparable the discoveries are from practical goals. I make no claim to being a bioengineering or biotechnology expert, but those who are refer to these breakthroughs as both scientific and practically oriented in the sense described by Cuevas Badallo:

(1) Michel Morange says that the experiment carried out at Stanford by David Jackson, Robert Symons, and Paul Berg and published in l972 in the *Proceedings of the National Academy of Sciences* marked the beginning of genetic engineering. In this article, Jackson, Symons, and Berg describe how they obtained *in vivo* a hybrid molecule containing both the DNA of the SV40 oncogene and the DNA of an altered form... that already included the *E. coli* galactose operon (Morange l998, p. 187).

(2) According to Morange (1998, p. 186), others disagree and credit earlier work of Werner Arber, Hamilton Smith, and Daniel Nathans, summarized by Arber (1979)on the use of restriction enzymes to cut or cleave DNA at precise points, of which the Berg groups work was a natural development.

The fact that Berg did not receive a Nobel Prize and his predecessors did, does not detract from the point made here. Both accomplishments have been recognized (Berg won other prestigious prizes) both as important scientific breakthroughs and as key techniques for future practical work in genetic engineering.

(3) Still following Morange (1998, p. 231), we come next to PCR, the polymerase chain reaction technique which Morange says (p. 242) "More than any other technique, has changed the work of molecular biologists."

Here is Morange's summary of how it has done so:

> In 1983 Kary B. Mullis developed a technique for amplifying DNA called the polymerase chain reaction (PCR). [See Mullis, 1990.] PCR can amplify virtually any DNA fragment, even if it is present in only trace amounts in a biological sample, thus allowing it to be characterized. It can aid forensic medicine by characterizing DNA molecules present in biological samples such as hair, traces of blood, and so on. It is sufficiently sensitive to permit the detection and characterization of the rare DNA molecules that persist in animal or human remains thousands of years old. This technique also makes possible a genetic diagnosis on the basis of a single cell... Finally, it permits the early detection of bacterial or viral infections (p. 231).

All these practical applications led one seemingly jealous previous Nobel Prize winner to call PCR a mere technical trick when Mullis won his Nobel in 1993. But Morange (1998, p. 242) clearly thinks it was a significant scientific breakthrough as well as a significant breakthrough in genetic engineering.

(4) In a more recent book, Morange (2001, pp. 64 ff.) talks about a completely different technique or set of techniques. The book focuses on gene function rather than genes in the abstract or genetic engineering; indeed, Morange says:

> My description of gene function is... as concrete as possible, giving a precise image of their functions in the most fundamental life processes: development, aging, learning, behavior, the establishment of biological rhythms, and so on (Morange 2001, p. 4).

And in that context one particular technique, so-called gene knockouts, seems particularly important to him.

> Inactivating [a] gene makes it possible to see in which tissues and organs its action is necessary. Conversely, when the product of a gene has been sufficiently studied... [even] fully described, it may seem unnecessary to verify the function *in vivo* by a knockout experiment. However, knockout experiments... have produced more surprises than even the most enthusiastic partisans of this new technique expected (p. 64).

In this case (these cases), the practical payoff is not usually bioengineering but some scientific discovery that may have an impact, say, on clinical medicine. So I may be stretching in bringing this in here, but it does seem to me that such gene knockout experiments represent another case of the kind of theory-practice combination that might exemplify what Cuevas Badallo would be seeking in a more complete philosophy of technology, here philosophy of biotechnology.

C. SUMMARY AND AN UNEXPECTED CONCLUSION

Summarizing what I have here suggested are the first steps toward a comprehensive philosophy of biotechnology, I will first refer to a more recent paper of Cuevas Badallo (forthcoming), in which she takes great pains to show that many contributions need to be taken into account in an adequate philosophy of technology (in general). Even Bunge's applied science model sometimes works, as do approaches that make scientific advances dependent on technological or instrumental advances (e.g., Pitt 2000) and a whole host of other approaches; Cuevas Badallo is, reluctantly, even willing to say that technoscience constructivist approaches (see Hughes, 1988) are sometimes useful. Her point is not that her engineering sciences approach is better than the others. All are necessary, and complementary, for an adequate and complete philosophy of technology in general or any particular technology or set of technologies.

Here I have emphasized, in my approach to an adequate philosophy of biotechnology (including bioengineering), the ethics and politics of biotechnology and genetic engineering, debates about genetic reductionism, and approaches to an engineering philosophy of biotechnology, for which I have borrowed ideas from Steve Goldman, Billy Vaughn Koen, and Cuevas Badallo. Biotechnology, combining these views, is a part of captive engineering (Goldman); is necessarily related to the state of the art at any given time (Koen says current genetic engineering is deficient in this regard), and involves key bioengineering theories/techniques (where I have supplemented Cuevas Badallo with references to historian of genetics Michel Morange). As Cuevas Badallo says for any technology, I would say biotechnology is highly complex and has a variety of complicated relationships with genetics and other biological sciences.

A final surprise in all of this can be seen if we return to the public furor over biotechnology that I used as a grabber at the beginning of the paper. Far from being illegitimate, public concerns about biotechnology and genetic engineering ought to be expected, even welcomed. Biotechnology may be the wave of the twenty-first century (as I have quoted the president of our university), but if the twentieth century has taught us anything, scientific and technological developments are fraught with social consequences. Originators of the Human Genome Project were wise to try to deal in advance with the ethical, legal, and social implications of the venture (the so-called ELSI program; see Marshall 1996, and the National Human Genome Research Institute 1997); and promoters would do well to consider the same for bioengineering, genetic engineering, and biotechnology generally. (Krimskys 1982, 1991, and 1996 leave broad openings for this.) If developments in biotechnology are to be truly valuable for society, there ought to be public input into their evaluation and management. This does not mean we have to take seriously every outspoken critic of biotechnology or genetic engineering, only that, in a democratic society, public discussion of such issues is welcome.

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