SCHOOL OF LAW
CASE WESTERN RESERVE UNIVERSITY

Case Western Reserve Law Review

Volume 19 | Issue 1

1967

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Professor Wald discusses the distinctions between organic and technological design and their political counterparts, democracy and planned society. Law must play an important role in his scheme to control experimentation with natural selection and manipulation of human genes. To this end, the author proposes the development of a principle of the "inviolability of the human germ plasm." With the prospects of atomic war and a population explosion, he further advocates birth control and free access to abortions.

BASIC TO ANY discussion of science and the law is the distinction between science and technology. Science is concerned with *knowing*; it is an attempt to understand all reality. In this sense our culture is committed to the pursuit of science as an unmitigated good. Any other view would be a plea for ignorance.

THE AUTHOR: GEORGE WALD (B.S., New York University; M.A. and Ph. D., Columbia University) is Professor of Biology at Harvard University, and recipient of the 1967 Nobel Prize in Physiology of Medicine.

Technology, however, the application of science to useful ends, is in a wholly different position. Technology is for *use*. In any properly functioning society every enterprise in technology requires judgment, in terms of that society's needs, aspirations, and goals. That should be true not only for new technological ventures, but in the review of all existing technology. Should one *know* all one can? — obviously yes. Should one *do* all one can? — obviously no.

The law, since it is concerned primarily with actions rather than with knowledge or belief, is more directly involved with technology than with science. Science might raise legal questions only through occasional practices in the pursuit of knowledge. For example, certain large-scale geophysical experiments might seriously affect man's environment — the oceans, the atmosphere, or even the stratosphere.[1] Experiments on living animals have raised recurrent issues, and there is a deep and increasing concern at present with establishing guidelines for experimentation with human subjects.

Apart from such special problems, however, it is as important to

[1] A recent experiment called West Ford raised strenuous discussion a few years ago. It involved strewing metal foil in large amounts into the stratosphere of our planet. A serious question, both here and abroad, was whether the scientists were sure of the ultimate consequence of such an experiment.

defend and promote the unlimited growth of science as knowing, as it is to control and guide technology to what our society recognizes to be desirable and useful ends.

Another dichotomy like that between science and technology is equally basic to this discussion. It is the distinction between technological design and what we may call organic design. Technological design begins with specifications, and does what it can to realize them in the product. One decides just what it is one needs or must do, and then proceeds in an attempt to do it, to fulfill those specifications.

Organic design, however, works by almost the reverse process. Its mechanism was described a century ago by Charles Darwin, and called *natural selection.* It involves four components: First, a mechanism of inheritance; second, a continuous outpouring of inherited variations in the form of mutations; third, a virtually continuous, rigorous competition among living organisms for the necessities of life, the "struggle for existence"; fourth, through the interplay of these forces, the "survival of the fittest": the constant elimination of those variations in organisms that work poorly, and the persistence of those that work well.

Natural selection is in this sense a process that depends upon editing rather than upon authorship. Biologists share the term "inheritance" with lawyers but the word means very different things to each. There is a world of difference between the reproductive act and making a will. For one thing, the donor in biological inheritance doesn't give up anything. On the contrary, in a very real sense, his substance is increased. Second, he has very little decision about what is to be inherited. Even the sex of his offspring is beyond his discretion. That whole process is largely one of chance by which, in the human case, one sperm out of the many millions in a single ejaculation fertilizes one egg in a long and random procession of ova.

Our concept of fitness as Darwin used it leaves much to be desired logically. It is little more than a tautology. When we, as biologists, are faced with some new mutation, unless it is a plain disaster for the organism that has produced it, we cannot predict at all what its effect on the species will be, whether it will survive or fail. One has to wait and see, and that leaves us in the strange and unsatisfactory position that the best way to estimate fitness is to see what survives. In fact, the best measure we have of fitness is the

numbers of offspring that themselves survive to sexual maturity and reproduce.

Organic design operates in the case of living organisms by this process of natural selection — by the survival of designs, so to speak. Design actually enters only in retrospect, as the result of the elimination of multiple alternatives. It is an altogether open ended process in which all solutions are tentative. If circumstances change, as they can be relied upon to do, natural selection offers the continuing opportunity for organisms to change accordingly.

At first glance, organic design seems enormously wasteful, slow, and uncertain compared with the technological procedures that are more familiar to us; but we should think well of it, for in living organisms it has produced by far the most intricate and effective mechanisms we know, and on a scale so minute as to make all technological products hopelessly crude by comparison.

In *The Descent of Man*,[2] Darwin did not hesitate to apply the concept of natural selection to human societies. There is a natural selection that operates there too. The characters take mainly the form of social mores and political institutions, and they are transmitted from generation to generation by cultural rather than organic mechanisms.

Some of our most cherished political beliefs are usually left in the form of arbitrary affirmations, having the quality of Luther's "Here I stand!" They can be defended more substantially from the viewpoint of natural selection, as applied to the practices and institutions of societies and nations. Cultural transmission is often so similar to genetic mechanisms in its effects that only careful experimentation can tell them apart — can distinguish nature from nurture. The law of course is one of the most powerful mechanisms of cultural inheritance.

Democracy, in its open endedness and capacity for change, whatever its other appurtenances, has the quality of an organic development which gives free play to variation and is endlessly responsive to new circumstances and conditions. On the other hand, the "planned society," for all its blandishments of logical design and efficiency, is a technological construction that rigidly fits one set of conditions. Democracy, as a political system, allows social natural selection. It can evolve as living creatures evolve, by experiment and by trial and error choices among multiple alternatives. A

[2] C. DARWIN, THE DESCENT OF MAN (1871). *See also* C. DARWIN, ON THE ORIGIN OF SPECIES (1859).

"planned society," on the contrary, must change according to plan, preconceiving the new procedures, and so preconditioning their outcome.

Natural selection also provides the most cogent defense of social and political tolerance. Uniformity offers no opportunity for evolution. Diversity is at the heart of the selective process and all adaptive change depends directly upon it.

It should be understood that the supreme value in evolution, whether biological or political, is not change as an end in itself. Rather it is *adaptation*, the continuing flexibility to meet new conditions. It is indeed something more, for even without change in the external conditions, the ceaseless pressure of competition causes a continuous trend toward optimization. One never knows when some organism, in its random mutations, may achieve some slightly more effective component or procedure. But whenever that happens, natural selection tends not only to preserve it, but to disseminate it within the stock. The traditions and institutions of an open ended and tolerant society offer a similar assurance of continuous optimization of its forms and practices.

At Harvard's tercentenary celebration 30 years ago, Dean Roscoe Pound of the Harvard Law School drew an analogy between the English common law, with its open ended system of tradition and precedent — seeing what works and retaining that while discarding what is unworkable — as an example of what I have here called organic design, in contrast with systems of codified law, more comparable with technological productions.

These distinctions are a necessary background for approaching what is perhaps our most serious problem, the possibilities opened by recent developments in science for practicing a technology upon man, not only upon his physical constitution through the manipulation and management of human reproduction and genetics, but upon his behavior and systems of belief through sophisticated conditioning procedures.

It is best to begin by dismissing one possibility that, though it has become common talk, is altogether fanciful. This is the thought that in the foreseeable future, or indeed ever, we are likely to manufacture living organisms from their components. It is true that, in confirmation of our present notions of the origin of life, it would be extraordinarily interesting to assemble experimentally a microscopic blob of living material, something I picture will look like an amoeba from which the nucleus has been removed. I think that some day

not too distant, that will be done; though it is usually surprising to nonbiologists to realize that far from this being a central problem in modern biology, I know no reputable biologist who is at present attempting it. Most scientists feel that though this will be worth doing eventually, it can wait until we have learned a little more about the attendant circumstances. But once a microscopic blob of protoplasm has been put together, that kind of experiment will lose its interest for biologists. I doubt that any of us will want to go on with it, even to the length of making an amoeba. It is much better to let amoebas make amoebas. The thought of any possibility of ever making man is pure fantasy.

A number of possibilities exist, however, for the control of human reproduction. Some of them are still dim, while others are already within our grasp. An example is the set of ideas surrounding "test tube babies." At present, nothing prevents the fertilization of human eggs outside the body. But, under any conditions yet achieved experimentally, such fertilized eggs would not develop far *in vitro*.[3] One would have to implant the early embryo in a foster mother who would bring it to term. It is altogether possible that a technology might be worked out in the future that would permit embryos to develop further, and perhaps eventually completely, in culture, but that is far from feasible now.

Another possibility in this regard is even further from realization. In 1952 Briggs and King performed the interesting experiment of removing the nucleus from a frog egg and replacing it with another nucleus taken from one of the cells of an early frog embryo. In about half the cases such eggs went on to develop normally. The transplantation of nuclei from later embryos proved much less successful, and how far one may eventually be able to go with such experiments, even in the amphibia, is still in considerable doubt.

Nevertheless, such experiments suggest the remote possibility that one might eventually be able to start eggs off with nuclei from somatic cells. If that ever became possible, one could thereby accomplish reproduction in the literal sense. What we now call re-

[3] Some years ago my good friend, the late Gregory Pincus, produced the first "test tube" rabbits from eggs that had not been fertilized, but were activated to develop by the manipulations involved in removing them from the female. Having been started in that way, they were implanted at an early stage into the uteri of other females which brought them through. These animals were therefore fatherless and born of foster mothers. Pincus, *The Comparative Behavior of Mammalian Eggs in Vivo and in Vitro*, 82 J. OF EXPERIMENTAL ZOOLOGY 85 (1939); Pincus, *The Breeding of Some Rabbits Produced by Recipients of Artifically Activated Ova*, 25 PROCEEDINGS OF THE ACADEMY OF SCIENCES 557 (1939).

production in higher animals is never truly that; offspring resemble parents to various degrees, but never duplicate them. This is because there are always genetic differences between them. So far as we know, however, nearly every cell in the body contains exactly the same genetic information as every other cell. Hence, if one could remove a bit of tissue containing one thousand cells from a person, and could inject a nucleus from each of them into an enucleated human egg, and then succeed in bringing each of the resulting embryos to maturity, one might produce one thousand identical individuals, in a sense one thousand identical twins. We could in that way produce one thousand Einsteins — or one thousand Hitlers.

All such possibilities are still remote, but there is already available and in some use the practice of artificial insemination of women with selected sperm. How much of this goes on at present is hard to discover, as are the arrangements made to obtain the sperm. It seems technically feasible, however, to establish banks of frozen human sperm and to offer women the opportunity of selecting sperm from a known donor. Frozen sperm are already in wide use for the artificial insemination of cattle, and I know of no serious technical difficulties to prevent the establishment of human sperm banks.

The point of these devices, present and foreseeable, is not to speed up the production of human beings. Most of us can agree that the tried and true methods are already producing too many. Rather, the point is the control of human inheritance. One could in this way achieve controlled human mating, in the sense of mixing selected eggs and sperm, ostensibly to improve the quality of the human stock.

Such proposals are being urged very vigorously in some quarters on the ground that one should not continue to leave such a critical activity as human mating to such random devices as in the past.

I view all such enterprises with strong misgivings. The elation in many quarters that goes with such proposals is merely a reflex action to something new — being new, it is progress; being progress, it is wonderful. In principle they are not new at all, but rather old and familiar: breeding by specification. This substitutes for natural selection the technological process that Darwin called "artificial selection"; it replaces organic design with technological design. This is the way in which we have made all our domestic animals. Applied to men, it could yield domesticated men. We have bred our domestic animals over many generations of controlled mating to be just what we want them to be — the pigs to be fat, the cows to give

a lot of milk, the work horses to be heavy and strong, and all of them to be stupid, for a clever animal can make a lot of trouble.

Are we now to begin to domesticate man, to make man a more highly standardized and more reliable, and hence a more useful product? And who is to decide the specifications? Useful to whom? And to what end?

Furthermore there is a serious danger that affects any living organism fitting any set of specifications too closely. Although such specifications might fit an organism ideally for a fixed set of conditions, the organism might thereby be less able to adjust to changed conditions.

The great merit of organic design and of the mechanisms of natural selection is their flexibility. The virtue in evolution is not change; the virtue in evolution is adaptation. The environment can be counted upon, one way or another, constantly to change and to present living organisms with new problems — and here we have the flexibility, the mechanisms to meet the new situations. All biologists tend to think that the penalty for overspecification is eventual extinction. Natural selection has its source in the constant outpouring of random inherited variations. A change of environmental circumstances, however sudden, can begin to select new elements in the population for survival, and so can turn a species in a new direction. Controlled mating to specification, by restricting variation, would tend to close off such potentialities for adaptation to unforeseen changes of condition.

I have argued elsewhere that the main source of what we conceive of as free will and human freedom, and its implication of responsibility, lies not in any conviction that human constitution and behavior are necessarily undetermined, but rather in the fact that they are unpredictable.[4] Human constitution is determined genetically, human behavior both genetically and through experience, with all its vagaries. To the degree that either of these processes, which up until now have contained large random components, are brought under control, these features of human existence are made predictable, and to that degree human freedom and responsibility are eroded.

Although I would not favor anything as simple as an out-and-out policy of hands off, I think that here one needs to proceed with the greatest caution, and with a strong understanding of the kind of

[4] Wald, *Determinacy, Individuality and the Problem of Free Will*, in NEW VIEWS OF THE NATURE OF MAN 16 (J.R. Platt ed. 1965).

structures and forces with which one is dealing. It is of basic importance to realize that we have become men through a process altogether different from technological design, and that from this point of view violence is done with the proposal to exercise technology upon man. Before tampering with this structure, it is important to recognize fully its nature and history.

Single-cell organisms reproduce simply by dividing and there is no necessary death for such organisms. They are potentially immortal; death comes as an accident but is not essential. An amoeba, for example, need never die, but can divide and redivide indefinitely.

When you consider multicellular organisms that reproduce sexually like human beings, then the situation that August Weissman, the 19th-century biologist, described is in force. Every such organism begins its life as a fertilized egg, which begins to divide and continues to divide until it eventually becomes an adult, mature organism. In the course of divisions, there develops both the body, termed by Weissman the soma, and reproductive cells — egg and sperm — which he called the germ plasm.

A new generation of a sexually reproducing organism commences when the sperm of the organism fertilizes an egg of the same species. When the newly created organism reaches maturity, its reproductive cells participate in the production of the next succeeding generation.

On this basis Weissman stated two great biological principles. He spoke of the first as the *isolation of the germ plasm.* We would now tend to state this principle in the form: genetic information goes only in one direction, always from germ plasm to soma, never from soma to germ plasm. That is why there can be no inheritance of acquired characters. An acquired character is a change in the body, in the soma, and there is no way of transmitting that into the germ plasm.

Wiessman called his second great principle the *potential immortality of the germ plasm.* The germ plasm represents a potentially immortal line. What we know as death is the discarding of bodies, generation by generation; the germ plasm goes on. The business of a body in these terms is to take care of its germ plasm — to feed it, to protect it, to warm it in a warmblooded creature, and eventually to mingle it with the germ plasm of the opposite sex. With this final act, having completed its work biologically, it can be discarded. That is death.

Every organism alive today represents an unbroken line of life

that stretches back to the first primitive organism on this planet; for if that line had ever been broken, how could we be here? By now that represents a line of life that stretches back something like 3 billion years. Recognizing this development for what it is, knowing something of how it has come about, one has every reason to exercise restraint in tampering with it.

One of the glories of modern biology is that at last we know something of what a gene is and what it does in living organisms. A gene is made of nucleic acid, composed of chains of units called nucleotides. Principally, the specific sequence of nucleotides in the gene determines the sequence of amino acids in a protein. For each protein in the body of an organism, there is such a determining gene. The proteins in turn are among the main bulk constituents of cells and organisms, and since they include all enzymes, they regulate and catalyze all the processes that go on in living things. In a sense, a living organism is the greatly magnified expression of the information contained in its genetic material, and that information exists in the form of specific sequences of nucleotides in the nucleic acids that constitute the genes.

The recognition of these relationships has raised the possibility that in the foreseeable future it may become possible to manipulate the genetic material directly by chemical procedures so as to modify the genes. As with all the developments already mentioned, real and potential, this presents an exciting challenge to some of the workers in this field. The problem is not with the knowledge, that we hope will increase speedily and without limit, but with the desire to apply it, and indeed to apply it to man. Rather than treating diabetics with insulin, or carefully regulating the diet of phenylketonuric children throughout their lives, would it not be far better to modify the mutant genes that have caused these hereditary conditions so as to cure not only the afflicted individuals, but, if one could perform that modification in the germ plasm itself, also their descendants? Granted, of course, that would be a great boon, but the problem is by no means so simple. It is already easy to modify the genetic material by a number of procedures — X-rays, mustard gases, and certain other chemicals — but not in a controlled way. All that one does by these means is to greatly increase the general rate of mutation. It is very difficult indeed to see how one is going to achieve the *directed* modification of individual genes in the foreseeable future. The task is so difficult that without any risk of being ultraconservative, I wonder whether that can ever be done.

Beyond that, however, we are sometimes offered the prospect that once such manipulations become possible, they need not be confined merely to correcting defective genes. They could in a real sense put human evolution under detailed control. One could produce mutations at will. Any such possibility would put into our hands the most refined method by which to remake man to specification.

I rather think that just as our respect for human life has bred the tradition, and embodied it in the law, that human life is to be preserved at all costs under all conditions, so too we must develop a respect for the human genetic material that will guard it from intervention. I would suggest considering a principle of the *inviolability of the human germ plasm.* It may be that some day we shall have the means and shall have sufficiently well established the grounds for some well-explored and well-controlled intervention; but the barrier should be high, and some such principle as this may provide the barrier.

Some recent advances in biological technology threaten to raise interesting problems for the law. One of them involves our concepts of life and death. As everyone knows, workable artificial hearts and artificial kidneys are already in use. Although we have these as yet only in crude, primitive forms, they surely will be greatly improved in time. How much of the human organism is replaceable in this way is at present anyone's guess. It is a little difficult until one gets used to the idea to insist upon the sanctity and dignity of a man, important parts of whom were made in a machine shop.

Another situation is already worrying lawyers. A number of provisions in the law become operative only at the time death occurs. For an obvious example, bequests in a will made "in anticipation of death" have special tax provisions that come into force only if the person making the will dies more than 3 years later. One could imagine a situation in which such a person at the point of death was provided with an artificial heart that kept the blood circulating, and perhaps sustained a few other manifestations of "life," until the 3-year limit had passed.

Within recent years procedures have been developed, notably by Audrey Smith of the Medical Research Laboratory at Mill Hill near London, for greatly lowering the temperature of a mammal and eventually resuscitating it without damage. Many problems remain to be worked out, yet it seems that this kind of procedure

will be made to work better and better over the years and might eventually be applied to man. All chemical reactions go more rapidly at higher temperatures. In general, a rise of temperature of 10° C. speeds up chemical reactions two to three times, and of course a lowering of temperature by 10° slows them by the same factor. To some degree, as was shown with fruit flies many years ago, the same rules apply to the duration of life; fruit flies tend to live about 2.5 times as long for every 10° C. that the temperature is lowered. If one brought the body temperature of a man into the neighborhood of 0° C., all the bodily functions would be in virtual abeyance; and if one could do this successfully, and eventually resuscitate him, one might in this way keep a person in a dormant condition indefinitely.

An additional overwhelmingly acute problem faces us now. The human enterprise is now threatened as perhaps never before by two developments: the prospect of atomic war, and the population explosion. One could suggest that the one eventuality be permitted to cope with the other; but I take it that this is an inadmissible solution. Both these problems have come upon us too rapidly to allow dealing with either of them gracefully. We are desperately pressed, and will have to improvise what solutions we can on the run. Unless controlled, they may bring to nothing the organic design that I have so greatly praised. Indeed, one of their byproducts, radioactive fallout, directly attacks the integrity of the germ plasm. Any principle of the inviolability of the germ plasm can hardly evade the necessity to control radioactive fallout.

Our present world population is already well over three billion and many of us already are finding the world overcrowded. At the present rate of increase, however, we are told that the world population will double again before the end of this century. One can only be grateful that suddenly, in fact with almost explosive suddenness, this issue has become a matter of wide and outspoken public concern, and that government, having sheered away from all contact with this subject in the past, has begun to display an open interest in it.

What can be done? First of all, of course, more widespread, indeed universal, dissemination of information on birth control is needed, and cheap and convenient contraceptives must be made available. I think we can be sure of increased progress in these directions within the next few years. Second, and perhaps ultimately more important, one needs free, convenient, and universal access

to abortion. We need not only to make abortions legal, and to overcome the very strong social prejudices against this practice, but also to cope with the real difficulties and dangers of the surgical procedures by which abortion is at present accomplished. Apparently the prospects are reasonably good for achieving an abortion pill within the coming years. The advent of such a device would change the entire situation radically, probably making abortion at once the preferred method of birth control. One could in this case replace the continuous demands of prevention with an occasional exercise of correction.[5]

It is quite possible that within the next 15 or 20 years we shall see all these things happen. I have, however, the strong feeling, though nothing tangible to support it, that if the next 20 years or so bring about a fair trial of these procedures in their most ideal form, it will prove only that all these methods are not enough to keep the world population within proper bounds. It would perhaps be advisable in any case to foresee the possibility of such an outcome, and to ask, what can we do then? It seems likely that this is a situation we shall have to face eventually. The only eventual solution that I can imagine is to make it illegal to have a child without a license. Such a suggestion seems utterly repugnant now. I hope it never proves necessary, but I fear that it may. It is perhaps not too early to begin to think through the problems that this would raise for legislation and the law.

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[5] *Cf.* Hardin, *The History and Future of Birth Control*, 10 PERSPECTIVES IN BIOLOGY AND MEDICINE 1 (1966).