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GENETIC ENGINEERING: A BIOLOGICAL TIME BOMB?

DUANE T. GISH*

Claims are being made that man will be able to eliminate genetic defects and eventually "control his own evolution" by a combination of eugenics and specific alterations in his genetic material.

While eugenics, or controlled human breeding, is possible, its beneficial effects would be limited or doubtful, and its practice would be socially unacceptable by the majority of the population.

In vitro fertilization with subsequent in utero implantation of the resultant blastocyst may some day be possible, but success may be limited, and the method most likely would be fraught with many dangers for the developing embryo.

Insertion of healthy genetic material into cells that are genetically defective would have limited benefit even if successful, and the results would more likely be disastrous rather than beneficial. While correction of faulty genes by "genetic surgery" may be theoretically possible, insurmountable technical difficulties will almost certainly forever prevent its use.

The idea that man may someday be able to alter specific human characteristics and thus "control his own evolution" is seen as science fiction rather than as serious science.

Introduction

In an editorial entitled, "Will Society Be Prepared?" in *Science,* 11 August, 1967, Marshall Nirenberg, Nobel Prize-winning scientist, stated that, "Cells will be programmed with synthetic messages within 25 years."

George W. Beadle, another Nobel Prize winner, in his book, *Genetics and Modern Biology,* said that "our knowledge is such that we could, if we chose to do so, direct our own evolutionary future."[1]

Immediately after a press conference called by Harvard biologists to announce that they had isolated a gene, the *Evening Standard* in London carried the headlines, "Genetic 'Bomb' Fears Grow." On that same day, another London paper, the *Daily Mail,* headlined a story, "The Frightening Facts of Life. Scientists find secret of human heredity and it scares them."

Gordon R. Taylor, a science journalist, has authored a book published in 1968 entitled *The Biological Time Bomb.*[2] Mr. Taylor attempts to answer the question, where are the biologists taking us? He apparently based much of his material on reports similar to the highly speculative predictions and scare stories quoted earlier. Taylor characterizes new discoveries of biologists "as earth-shaking as the atom bomb."

He indicates that the results of these discoveries are not going to explode in some distant future, but during the lifetime of many who are living today (some of whom, he claims, may live to be 150 years old!). He anticipates the early possibility of a child being born 100 years after his father's death; human beings conceived and nurtured into life by processes in which sex plays no part; elimination of diseases caused by genetic defects; and even control of human intelligence through genetic engineering.

There is real cause for alarm, of course, if indeed it will be possible at some time in the future to control human intelligence, emotions, and personality via genetic engineering. The biological, psychological, political, ethical, and moral problems generated would be immense in scope, and perhaps insoluble. The possibility that such developments would be used to advance the public good rather than as a means to acquire power and control over one's fellow men

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would be no greater than that demonstrated by man through his use of explosives, atomic fission, and other technological developments utilized in modern weaponry.

The purpose of this paper is to expose the speculative nature of popular predictions related to genetic engineering and other attempts at biological control.

Proposed Methods of Genetic Control

Control of human reproduction and of human genetics is being advocated or anticipated on the basis of several approaches. A method recommended by some scientists, and which would require the development of no new technology, is controlled breeding involving sperm banks and artificial insemination. A second process is that of cloning, or cell fusion.

As we shall see shortly, cloning has already been performed with animal cells, and some think that application of this technique at the human level is only a matter of time. *In vitro** fertilization, or the production of so-called test tube babies, has been carried out to a very elementary stage, and has been envisioned as the solution to some types of sterility.

A much more remote possibility, involving the development of knowledge and technology not now available and perhaps forever inaccessible, is the technique of genetic engineering, or the modification and synthesis of genes in order to eliminate genetic defects and eventually to remodel man along predetermined lines.

Eugenics: Controlled Human Breeding

Eugenics is defined† as the science and art of improving human breeds by so applying the ascertained principles of genetics and inheritance, as to secure a desirable combination of physical characteristics and mental traits in the offspring of suitably mated parents. Human reproduction at the present time, however, except in relatively few cases, results from a process of random mating. That is, a marriage partner is generally selected without a prior investigation of that partner's genetic background. People just fall in love, get married, and have children.

The late Herman J. Muller, who was a geneticist at Indiana University, is numbered among those who have proposed that such practice be changed. Dr. Muller maintained, for example, that the means exist right now for achieving a much speedier and significant genetic improvement of the human population by the use of selection than could be effected by the most sophisticated methods of genetic engineering that might be available for the next hundred years or so.

Muller strongly advocated that sperm banks be established containing semen from individuals with documented characteristics. Prospective mothers, with the consent and counsel of their husbands and foster fathers-to-be, would then select semen for artificial insemination from the donor possessing the characteristics desired for the future child. This method of conception, it is maintained, would improve the human race by minimizing the incidence of genetic defects and by improving genetic fitness, resulting in superior physical, mental, and emotional qualities.

Such a process would, if followed by most of the population, minimize, though it would not eliminate, genetic defects. The possibility of a positive effect, or enhancement of desirable qualities, is far less certain.

In animal and plant breeding, we are interested in a relatively few and easily detectable and measurable qualities, such as disease resistance, reproductive capacity, quantity and quality of meat, egg, or milk production. The qualities we would like to see in our children are much more elusive genetically. A splendid physical specimen may not be overly bright. A very bright child may be a bore or a little monster.

The story has been told that a beautiful entertainer proposed to George Bernard Shaw that they have a child, suggesting that the combination of her beauty and his intelligence would produce an unusually gifted child. Shaw declined, with the comment, "Supposing it had *my* looks and *your* brains"!

In addition to uncertainties concerning the attainment of really significant improvement in desirable qualities through selective breeding, the loss of genetic fitness by such a process is a very real possibility. Selective breeding in animals results in a reduction in the total number of genes in the breeding population, with a loss of genetic variability. For reasons not completely understood, this results in a lowered ability to survive under various conditions. Domesticated animals that have been subjected to selective breeding do well because man cares for all of their needs. If these animals were released into the wild, however, most would not survive.

The same results might be obtained in the case of man. The practice of eugenics might lead to a race of people with an increased frequency of certain desirable qualities who, at the same time, had reduced resistance to certain diseases, and who might be unable to cope with mental and emotional stresses.

All of the above is merely academic, I believe; for except for those few who might want to take advantage of this method because of sterility of the husband, only a small minority would ever

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**In vitro* means external to a living organism, while *in vivo* refers to a process taking place in an intact organism.

†Funk and Wagnall's New Practical Standard Dictionary, Funk and Wagnall's Co., New York, 1946.

agree to surrender their sharing in their own children's procreation. My children may not be the most beautiful and intelligent in the world, but they are *my* children, and I would have it no other way. Muller and others who advocate the practice of eugenics are simply out of touch with the real world. Furthermore, consistent practice of "artificial insemination" in cattle has led to the production of malformed "bulldog" calves which are routinely destroyed (culled) in the breeding program. Such a result and program among human beings would be unthinkable.

Cloning, or Cell Fusion

Successful experience with cloning, or cell fusion, using cells from frogs has encouraged some to believe that this technique may someday be applied to humans. Dr. J. B. Gurdon, a biologist at Oxford University, has performed some highly interesting experiments in this field[3]

Gurdon, using a very tiny pipette, removed the nucleus from a frog egg. The nucleus contains much of the genetic material of the cell, of course, and thus an egg could never develop without a nucleus. Gurdon removed the nucleus from one of the cells of a frog embryo and inserted it into the egg which had been deprived of its nucleus. The egg then was allowed to develop. In some cases the egg developed to the tadpole stage only, but in other cases fertile adult male and female frogs were produced. Many experiments were unsuccessful, of course.

Usually nuclei from unspecialized embryonic cells were used. In a number of cases, successful experiments were carried out using nuclei derived from compltely differentiated cells of the intestinal epithelium of tadpoles. These cells were intestinal cells, yet when nuclei from these cells were placed in egg cells which had had their nuclei removed, these eggs in some cases developed just like normal eggs, producing fertile male and female frogs.

This experiment demonstrated what scientists had already suspected. All cells from an animal, whether skin, intestinal, muscle, nerve, or liver cells, or any other kind of a cell with a nucleus, contain all the kinds of genes that were originally present in the fertilized egg that gave rise to the adult animal. During the development of the animal from the egg, by some mysterious process, cells become programmed in such a way that some develop into skin cells, some into bone cells, others into muscle cells, etc.

Apparently in each case only a fraction of the genes present in the nucleus of each cell are activated, the remainder being suppressed. The particular set of genes that are activated in each type of cell determines what kind of a cell it becomes. Scientists have no idea whatsoever how all of this takes place. They may never know. It is one of the greatest marvels of God's creation.

The genes in the nucleus of the intestinal cell taken from the tadpole had already been programmed, of course, to produce an intestinal cell. When this nucleus was placed in the enucleated egg cell, this programming was reversed. All of the genes were able to function, and a complete frog was produced from the egg.

Some scientists are saying that extension of this process to man is only a matter of time. They are saying that someday we will be able to take cells from a human donor, remove the nuclei, place these nuclei in human eggs from which the nuclei had been removed, implant each such egg in the uterus of a mother-to-be, and allow each egg to develop into a baby that would grow up to be a perfect copy of the donor. Poof! Instant Einsteins if you wish! Or perhaps a dozen Van Cliburns! A militaristic dictatorship might require its womanhood to produce copies of its finest soldiers and generals.

Although we cannot positively say that this process will never be possible at the human level, we wish to point out that the frog is an amphibian, and such a technique may never succeed with mammalian cells and, in particular, with human cells. There *is* a vast difference, after all, between a frog egg and a human egg. The two eggs are designed to develop under entirely different conditions. Such manipulation might cause the human egg cell, if it developed at all, to give rise to a monster rather than to a normal human being, because of defects during embryological development.

Furthermore, the cells used in the frog experiments were derived either from embryos or from tadpoles. Although the cells taken from the tadpole were fully differentiated, that is, they were taken from a definite type of tissue or organ, we do not know whether nuclei derived from cells of an adult frog would have resulted in a successful experiment. Perhaps irreversible changes in cells take place during the metamorphosis of a tadpole into an adult frog.

I don't think we need to lie awake at night worrying about cloning of human cells. People won't be produced any faster this way than by the normal reproductive process, and the results, if a normal healthy individual is produced, would be perfectly predictable. The child would be an exact genetic copy of the person donating the nucleus—no better, no worse.

In Vitro Fertilization—Test Tube Babies

Some medical scientists have been investigating fertilization of human eggs *in vitro*, that is, outside of the body. This is often referred to as attempts to produce test tube babies, but it must be remembered that in the process now being in-

vestigated, only fertilization would take place outside of a human body. The production of the sperm and ova and the subscquent development of the embryo all would take place inside human bodies.

Biologists have been fertilizing eggs of various species *in vitro* for many ycars, although, as yet, successful implantation of such fertile eggs in an animal and development of the embryo to birth has, as far as I know, never been accomplished. Failure to go beyond such limited success in animal research does not bode well for success in human beings.

Many difficult problems associated with such a process have so far caused success with human cells to be very limited. All the eggs a woman will ever produce come from tissue present in her ovaries at birth. A generative cell must undergo several divisions before a mature egg, or ovum, is produced (the other cells produced are discarded). Secretion of certain hormones are required before the ovary can be induced to release an ovum. Certain substances, found in the female reproductive tract, must be present to enable the sperm to penetrate the ovum in order for fertilization to be consummated. Carefully controlled conditions arc required for subsequent development of the fertilized egg.

Dr. Robert G. Edwards and Dr. Patrick S. Steptoe, both of Cambridge University, arc among the leaders in work with human cells. Dr. Edwards has fertilized human eggs in vitro and has succeeded in developing them to the blastocyst stage.[4] This is the stage normally reached about six to eight days after fertilization, and it is at this stage that implantation in the uterus usually takes place during normal reproduction. Attempts may soon be made to implant such a blastocyst in a human uterus. This would first be tried in a woman who had been infertile or barren because of blocked oviducts. The egg would have been obtained from her ovary and the sperm from her husband, of course.

Such a process, if ever successful, would doubtfully become routine. Many failures could be expected along with the successes, and the medical and laboratory procedures required would be very costly. The procedure would allow women to bear children who had been barren because of failure of their ova to reach the normal site of fertliization. It would even enable a couple to hire another woman to bear their child, a so-called "surrogate mother."

This might be done in a case in which a woman, although capable of producing fertile ova, is for some reason physiologically unable to bear children. This method might even be utilized by women who are capable of bearing children and desire children, but who do not wish to bear children themselves.

Whether babies will ever be produced by *in vitro* fertilization cannot be predicted. Timing would be very important for successful implantation of the blastocyst in the uterus. In the normal monthly cycle, a single egg usually erupts from one of the ovaries. The space in the ovary from which the egg erupts develops into what is called the corpus luteum.

The corpus luteum secretes hormones that are required for the implantation of the developing egg in the wall of the uterus. Absence of this secretion, or poor timing, would result in an unsuccessful pregnancy. The *in vitro* manipulation of the egg and resultant blastocyst might result in either spontaneous abortion or the birth of a defective child.

Work along these lines should be no cause for alarm. If successful, some effect on birth rate would result. This procedure would offer no opportunity, however, to significantly alter or control human reproduction.

Some scientists have even visualized the day when babies will be developed entirely outside of a human body—true test tube babies. In a few cases it has been possible to keep an animal embryo alive for a few days after removal from the uterus. While it might be worthwhile to develop methods for keeping premature babies alive by some sort of artificial means until full term is reached and development is complete, it seems silly to even think about trying to produce real test tube babies.

After all, God has already provided the safest, surest, most satisfying way of producing babies—mothers. Even if it should ever become possible for a human being to be produced outside of a human body, which is unlikely, complex medical and technological procedures would be required. This would demand the use of expensive equipment, facilities, and personnel for the nine months required to develop the fetus. The cost would be prohibitive. Of what practical use is a synthetic method that produces a product at a cost many times that of the natural product?

Genetic Engineering—Repair of Defective Genes

In a section on "genetic surgery," in his book *The Biological Time Bomb*, Taylor quotes a Professor Tatum as reporting that there would be only "minor technical difficulties" involved in inserting genetic material into germinal cells. Taylor's way of telling things helps to sell his books, but does little to inform readers concerning the nature of the real world. Inserting genetic material into germ cells with retention of viability more probably will be enormously difficult. To do so in such a way as to obtain predictable and favorable results may well prove to be impossible.

In a news account of experiments by British

scientists in which genetic material derived from chick embryo cells was inserted into somatic cells of a mouse (all cells in an animal except germ cells are called somatic cells), *Nature* emphasized that ". . . although these experiments offer the exciting prospect (in theory at any rate) of evolving a therapy for mutant somatic cells, there are formidable, and very possibly insurmountable, objections to developing from them a technique which would apply to germ cells."[5]

There is quite a difference between "minor technical difficulties" and "formidable, and very possibly insurmountable objections"! Furthermore, getting the stuff into a germinal cell is only one small part of the problem. Let us take a closer look at this matter of correcting genetic defects using "genetic therapy" and "genetic surgery."

There are at least 1500 known genetic defects which cause crippling conditions or death in human beings;[6] such as,

hemophilia, a blood-clotting deficiency;

sickle-cell anemia and thalassemia, blood disorders;

phenylketonuria, a single enzyme deficiency which results in complete arrest of mental development in a newborn within a few weeks if not detected and treated;

Tay-Sachs disease, another condition caused by lack of a single enzyme and which causes general and rapid deterioration of the nervous system in babies and death within a few years; and,

juvenile diabetes, caused by failure of the Beta cells of the pancreas to produce a sufficient quantity of insulin.

There are about 140 amino acids in each of the four proteins (two each of the "alpha" and "beta" proteins) that combine to form hemoglobin, the oxygen-carrying protein of blood. In sickle-cell anemia, the amino acid at position #6 (glutamic acid) in the beta chain of hemoglobin is replaced by another amino acid (valine). This seems like a very minor change, but when the faulty gene causing this condition is inherited from both father and mother, the condition is fatal, usually within a few years of birth.

Genetic engineering in this case would consist of attempts to replace the faulty gene with the normal gene. Ultimate treatment would consist of an excision of the faulty section of the gene and insertion of the correct structure. The former might be called genetic therapy and the latter, genetic surgery. Limited genetic therapy may someday be possible, but insurmountable technical difficulties seem to render genetic surgery outside of human capability.

Special Methods of Cell Culture

The very interesting experiment performed by British scientists referred to earlier is described in detail in *Nature New Biology*.[7] The Oxford scientists, A. G. Schwartz, P. R. Cook, and Henry Harris, inserted small amounts of healthy genetic material from chick embryos into mouse cells that were deficient in one of its enzymes because of a genetic defect. The chick cells had the normal genetic material which codes for this enzyme.

The incorporation of this genetic material into the mouse cells permitted them to produce the enzyme. Most of the hybrid cells died but a few survived. They grew in cell culture and were now able to produce the enzyme in which they were previously deficient.

In this and similar experiments the cells were grown only in cell culture. None were implanted in an animal. It is hoped that eventually, for example, cells from the pancreas of a diabetic could be removed, treated with genetic material from a normal individual, grown in cell culture and then re-implanted in the pancreas of the patient. Such cells, it is hoped, would give rise to pancreatic tissue producing a normal supply of insulin.

Such a procedure in man most likely would actually be disastrous. First of all, the chick embryo genetic material in the British experiment was complexed with an inactivated mouse virus to carry it into the mouse cells. This technique of complexing with a virus to transport genetic material has been used by other investigators.

The presence of this viral material (DNA or RNA), even though inactivated, could potentially be very harmful. No one can really predict what effect such material might have on cells placed in human beings. Such cells might even turn out to be cancerous.

Since these hybrid cells would contain an enzyme and other material from foreign cells, the placing of such cells in an intact animal or human body almost certainly would stimulate the body's immunological defenses. Even in those cases where all human material was used, the hybrid cell might be antigenic to the recipient.

White blood cells and antibodies would be produced which would attack and destroy the hybrid cells. Not only would this result in failure of the attempted genetic therapy, but severe allergic reactions might occur.

Other less predictable but harmful effects might result. The final effects of such "therapy" more than likely would be far more severe than the original defect. Would you permit your child, even though suffering from a defect, to be used as a guinea pig in some such experiment?

Experiments on genetic therapy have been carried out so far only on somatic cells. Even though eventual success is highly unlikely, such therapy,

even if successful, would be of immediate benefit to the patient only. His germ cells would still carry the genetic defect and would be passed on to his children. Such treatment would actually increase the incidence of genetic diseases by permitting such genetic defectives to live and to reproduce.

It is highly doubtful whether sperm or egg cells in which genetic material had been inserted could live to produce a normal adult. The limitations and dangers in such a procedure have already been discussed in the section on cell cloning or fusion.

Genetic Engineering—Genetic Surgery

The chances of success with "genetic surgery" is even more remote than that with "genetic therapy." Genetic surgery would consist of an attempt to correct a faulty gene rather than to replace or supplement it with a healthy gene. Success must be obtained with a whole series of procedures before genetic surgery would be possible. The probability of success with each of these would be exceedingly low. Improbability piled on improbability equals impossibility.

In the nucleus of every human cell there are possibly several hundred thousand genes. At present we do not have the slightest idea which gene is which. How are we to "lay our hands" on the particular gene needing correction? Even if we knew which gene is which, how would we separate it from the hundreds of thousands of other genes in order to isolate it for treatment?

After having solved these two formidable problems we still would not have the slightest idea in most cases what to do in order to correct the defect. The particular genetic defect is known in sickle-cell anemia and in a few other cases, and geneticists thus know what needs to be done. But what is wrong with the genes of a hemophiliac? What defect causes diabetes? Answers to these and similar questions must be obtained before attempts can be made to correct these and most other genetic defects.

Now supposing we have located and isolated the faulty gene, have pinpointed the defect and know what needs to be done to correct the defect. We have no way at the present time to selectively make the change required and it is almost certain that no such method will ever be developed.

Most genes consist of several thousand sub-units, or building blocks. These sub-units are linked together like the links in a chain. There are only four different kinds of sub-units (called nucleotides). In other words, the genetic code is constructed from a four-letter alphabet. In a gene consisting of 4,000 nucleotides, there would be roughly 1,000 of each nucleotide (proportions vary in each gene).

In almost all genetic defects only a single one of the several thousand sub-units or nucleotides is faulty and would require replacement with the correct sub-unit.

If we designate the sub-units in the gene by the letters A, T, G, C, we would have roughtly 1,000 A's, 1,000 T's, 1,000 G's, and 1,000 C's distributed in a particular sequence in our hypothetical gene. Now let us suppose that the genetic defect could be corrected by replacing one of the A's at a specific point with a G. Let us say that this A is at position 3163 along this chain consisting of 4,000 sub-units.

There is no procedure available, or even conceivable at present, for effecting one particular sub-unit out of thousands without indiscriminately affecting others. In the above example, we would have no way of replacing the A at position 3163 without randomly replacing other A's scattered along the chain.

Since chemical reagents, radiation, and other agents used to alter chemical structure act randomly, no conceivable method would allow their use to make selective changes in genetic structures. Other more selective methods for altering chemical structures in genes may someday be developed but none are on the horizon today.

Furthermore, selectivity in genetic engineering must be absolute. No mistakes must be made. If the method used is slightly slipshod, a genetic nightmare might result rather than a genetic miracle. People who speak airily about genetic engineering just have no idea what the real problems are.

In summary, it may be said that while genetic therapy and genetic surgery may some day be theoretically possible, putting theory into practice may be prevented by a series of practical impossibilities. It is a dream that will most likely never be realized.

Genetic Engineering—Synthesis of Genes

Some scientists are saying that the ultimate solution for the problem of genetic defects is the synthesis of an entire gene. Rather than attempting to correct a genetic defect in a gene, normal genetic material would be synthesized in the laboratory and inserted into cells derived from an organ of the patient. Then, as described in the previous section, these treated cells would be grown in cell culture and later reimplanted in the defective organ. Many of the same limitations encountered with gene therapy discussed earlier would be faced in this method of treatment.

Furthermore, the difficulty in synthesizing a gene containing hundreds to several thousand sub-units, each of which must be put in its proper place with absolute precision, would be inconceivably great. A team of scientists have synthe-

sized a genetic fragment containing less than 80 sub-units. The synthesis was long and difficult, requiring many months of work by a team of researchers, and only a tiny amount of product was obtained. No doubt the material was not pure, but contained many molecules of faulty structures. Comparing the synthesis of a genetic fragment with 80 sub-units to the synthesis of a gene with several thousand sub-units is like comparing the construction of a one-story frame house to the construction of the Empire State Building. The tools that suffice for one would hardly suffice for the other.

The scheme that really excites the imagination, and which spreads alarm among laymen, is the idea that someday it will be possible to synthesize a whole complex of genes, insert them into germ cells and thereby produce offspring with altered physical and mental characteristics. We would then be able, it is said, to "control our own evolution." Such a possibility is so remote that there is really no cause for excitement or alarm.

The genetic factors controlling complex organs, intelligence, and personality are what we know the least about. In fact, it can be said that we know nothing about them, except that they are complex. Most characteristics in the human, in fact, are not controlled by a single gene, but are under the control of many genes. These characteristics are said to be polygenic. Furthermore, most genes effect, or help to control, more than one characteristic. It can be seen that the genetic apparatus of the human, or of any other animal, is inconceivably complex.

In addition to not knowing which gene is which, we don't have the slightest idea how to alter a gene in order to obtain a specific result. Altering a single gene would almost certainly upset the balance in the gene complex with which it is associated, producing monsters and mental defectives.

One Gene—One Characteristic: Impossible

Since most genes affect many characteristics, it would be impossible to synthesize a gene tailored to alter one characteristic without effecting others. A change in a gene which was tailored to improve eyesight, for instance, might result in an impairment in, or loss of, the sense of smell, if that gene participated in control of both of these organs. Deleterious effects on every characteristic governed by this gene could result, of course.

To change a characteristic that is under polygenic control, and most are, as we have mentioned, it might be necessary to alter every one of the genes in the gene complex controlling it in order to produce the effect desired. Imagine the problem, if one's imagination can stand the strain, of fathoming the specific changes that must be made in these genes in order to produce the desired effect, synthesizing each one of the genes, inserting the synthetic genes into a germ cell, and finally developing the germ cell into a human being! Science fiction, yes. Worthy of serious consideration? No!

At this point it would be well to hear from Dr. George Gaylord Simpson on this subject. Being the dean of the world's evolutionary paleontologists and an atheist, it could hardly be said that he shares our view of man, his origin and his future. If some should claim that our views are prejudiced by our Christian convictions, it can certainly be said that Simpson's views are not similarly affected. In an article published just a few years ago. Dr. Simpson stated,

> Most radical is a third suggestion about genetic engineering, that it may become possible to make genes to order and to insert them in human germ cells so that they would henceforth be inherited. This has had some sensational publicity and has also been viewed with alarm by those who like to view things with alarm. The excitement is premature, to say the least. Just a few of the impediments are: that we do not now know the actual structure of any human gene; that we do not know how to insert or replace genes in germ cells; that we do not know precisely how any gene produces such important traits as intelligence or temperament, or for that matter even such simple characteristics as stature; that the genetic system is an interacting whole so that insertion of a synthetic gene if it worked at all would have unforeseen and probably disastrous results. It is that last point that suggests that genetic synthesis, if possible, would be more likely to work for the public ill than for the public good."[2]

Professor Simpson agrees with us, therefore, that scientists have yet to find the secret of human heredity, and that there is indeed little to fear that a genetic bomb is about to explode in human society.

Man, in his ego, wants to play God. He dreams of unlimited potentialities through his own devices, but he is doomed to disappointment.

> Know ye that the Lord He is God; it is He that hath made us and not we ourselves. . . ." (Psalm 100:3)
>
> I will praise thee; for I am fearfully and wonderfully made. . . ." (Psalm 139:4)

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HOW MUCH LIKE ENGINEERING IS "GENETIC ENGINEERING"?

HAROLD ARMSTRONG*

Introduction

Every now and then one reads or hears something about "genetic engineering." Rather extravagant promises are made; such as, prevention or cure of certain diseases or changes in men and animals in ways which are supposed to be beneficial.

Such manipulation is often viewed with alarm. Rarely is it pointed out that what can be done in this way is at the present limited, and that there is no guarantee that much more will be possible in the near future.

However, in 1971, two authors have pointed out that some restraint is in order in talking about medical uses of such techniques. There are only a few genetic troubles which it seems feasible to consider curing by genetic manipulation; and, there is always the possibility that such manipulation might have undesirable side-effects. S. M. Fox and J. W. Littlefield concluded:

> The promises offered by the proponents of gene therapy largely ignore its limitations and hazards. To mislead the public in this regard risks another period of disappointment and reaction. . . . Let us not do to ourselves what we have done to our environment. Let us now seek public support for research toward a better understanding of normal and abnormal human biology, rather than promise quick glamorous cures.[1]

Authors of a more recent article likewise urge caution.[2] They point out that benefits to be expected from gene therapy are limited, and that it is not at all certain what side-effects there might be.

When I started to write about this matter, my first inclination was to dismiss most of what is written about "genetic engineering" as wildly extravagant, and to insist that, whatever it may be, it is not engineering. However, a friend pointed out that I could not ignore that, call it engineering or what you will, plant-breeders (and also animal-breeders) certainly have substantial accomplishments to their credit. At the same time it occurred to me that often there are two stages to engineering, and that the plant-breeder's work, for instance, might quite fairly be compared with one of the stages.

Two Stages of Engineering

Two stages of engineering show up especially well in electronics. Some engineers design and make the components: transistors, and so on, for instance. Other engineers take these components and assemble them into what we might call systems; a radio receiver, in this sense, would be a system. It is true that recently the introduction of integrated circuits has, in some cases, blurred the distinction between the two stages; but the illustration will still serve our purpose.

In view of this distinction, will it not be agreed that the genetic engineering which is actually done, in plant-breeding for instance, corresponds to the second stage of engineering? There are physical features of plants, desirable or otherwise, which it is known can be inherited; these are the components. The breeder, by crosses, assembles the desired features into the "system," the hybrid plant which is produced.

Among roses, for instance, which have been bred very extensively, the components might be such things as glossiness of the foliage, a certain color, a certain shape of bud, and resistance to diseases. Desirable and undesirable features are likely, at first, to be found together; the breeder tries to eliminate the undesirable ones and keep the desirable.[3, 4]

Breeders Utilize "Components"

In all this, the breeder is just using the features —the "components"—which he can find in the various varieties of living plants. It may well be that some of those features arose from mutations. So it may be worth his while to bring about a great many mutations in a short time, and to see whether any of them are useful to him. Of course, this has been done.[5]

But still, this is hardly what we have called the first stage of engineering. It is more as if, during the assembling, one were for instance to heat

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