THE LIMITS OF EXPERIMENTAL KNOWLEDGE: A FEMINIST PERSPECTIVE ON THE ECOLOGICAL RISKS OF GENETIC ENGINEERING

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Synopsis—The introduction into the environment of genetically engineered organisms can pose a threat to human health or ecological networks. This study analyses the manner of origin of these risks, starting with a reconstruction of the theoretical and methodological approach of modern science to natural phenomena, in order to elucidate the epistemic background of experimental science. Some characteristics of genetic engineering are outlined, before examples are discussed to illustrate some contradictions between a reductionistic understanding of biological phenomena and empirical findings. The next step points out the consequences which are to be expected if the discrepancies between theoretical concepts and empirical data are not recognized. A short explanation of the theoretical meaning of the term *context* follows, before some of the implications are discussed which result from ignoring the contextual nature of genetic information. The background for this analysis is founded in a feminist critique of the theoretical and methodological approach of biology to nature. Specific reference to the work of other feminists is made mainly in the final section.

Synopse—Die Freisetzung gentechnisch veränderter Organismen in die Umwelt kann eine Gefährdung für die menschliche Gesundheit oder fur okologische Zusammenhange darstellen. Ausgehend von einer kurzen Rekonstruktion des theoretischen und methodologischen Zugangs der modernen Naturwissenschaften zur Untersuchung natürlicher Phänomene, werden in dieser Studie die Entstehungszusammennänge solcher Risiken analysiert. Einige der Charakteristika gentechnischer Ein-griffe werden dargestellt bevor anhand einiger Beispiele verschiedene Widerspriiche zwischen einem reduktionistischen Verstandnis biologischer Phanomene und empirische Beobachtungen ver-deutlicht werden. Die möglichen Konsequenzen, die bei Nichtbeachtung dieser Widersprüche zwischen theoretischen Konzepten und empirischen Befunden zu erwarten sind, sind Gegenstand des nächsten Schrittes. Die Erläuterung des Begriffes "Kontext" bildet die Grundlage für die Diskussion der Implikationen, die aus der Nichtbeachtung der Kontextgebundenheit genetischer Information erwachsen. Hintergrund der voliegenden Analyse ist die femistische Kritik theoretischer und methodologischer Prämissen der Biologie, obwohl spezifischer Bezug zur Arbeit feministischer Theoretikerinnen hauptsächlich im letzten Kapitel hergestellt wird.

INTRODUCTION

Microorganisms are categorized into four groups, according to their risk potential for humans, animals or plants (WHO, 1979a,b). The safety measures which must be applied when handling these microorganisms are related to the degree and type of risk associated with each respective group. The classification of microorganisms is, therefore, conducted on the basis of known levels of safety and danger, reflecting longstanding empirical proof, and is not, therefore, based on theoretical considerations. This concept has been applied to work with organisms which have been altered by means of genetic engineering. Here, a manipulated organism is in principle classified on the basis of the host organism and the transplanted gene, that is, according to the additive model (Kollek, 1988a, p. 113, 1988b). It is questionable, however, whether this concept, which is characteristic of conventional biotechnology, can be applied to work with genetically engineered organisms. Nevertheless, it is accepted widely by legislative and executive bodies. Since the risks of genetic engineering will affect all of us, it is necessary to scrutinize whether it is an adequate basis for the evaluation of the risks associated with genetically engineered organisms.

THE EPISTEMIC BACKGROUND OF EXPERIMENTAL SCIENCE

According to the traditional ideal of scientific inquiry, reality should be perceived by the researcher during the process of research as correctly, completely, and objectively as possible. Methodological rules and standardized processes are designed to optimize this process of perception. Some of these basic rules were defined in 1630 by the French philosopher Rene" Descartes. They were designed to guide theoretical or other approaches to mathematical phenomena in the pursuit of knowledge (Descartes, 1972). Although Descartes later reflected critically on the epis-temic significance of these rules, they represented for a long time, and to a certain extent even today, the basis of scientific methodology.

The first rule asserts that it should be the goal of scientific studies to orientate perception in such a way that it can generate objective knowledge about all existing objects and phenomena (Descartes, 1972, p. 3). In other words, conclusions drawn by means of scientific logic and methodology can be claimed to be true and objectively given. The second rule prescribes that only those objects or phenomena should be subjected to scientific inquiry which can be approached by scientific means (Descartes, 1972, p. 5). This rule defines the domain of scientific inquiry, but by defining the sphere which can be perceived by scientific means, it implicitly also defines the phenomena which are relevant to the scientist. Phenomena which can not be approached or examined by scientific methods are not recognized as fields where knowledge can possibly be acquired.

The first two rules outline the scope of science. In his fourth rule Descartes points out the necessity of methods for the acquisition of systematic knowledge, and goes on it explicate this in the fifth rule. The most important task of methods is the classification of phenomena in order to reveal relevant characteristics (Descartes, 1972, p. 16). One must adhere to this principle if complex phenomena, intricate circumstances or hypotheses are to be subjected to scientific examination. They must be reduced step-by-step to more simple phenomena, processes, or interactions. On the basis of knowledge about the most simple elements of a phenomenon it should then be possible to reconstruct them by reconstructing the process of reduction.

Descartes designed these rules in order to solve problems of mathematics and physics. Furthermore, it was his intention to rationalize scientific discourse and to confront the widespread practise of wild speculations about natural phenomena with a systematic search for truth. In the further development of science, this approach also prevailed in other disciplines, where it was applied to analysing complex problems and to syste-matising empirical phenomena. The systematic analysis of repeatedly observed phenomena or events—such as the appearance of comets or the distribution of flower colors after cross breeding of red and white pea plants—led to the definition of rules and principles which were believed to influence and control those natural phenomena.[1]

At the beginning of the 17th century, Francis Bacon, considered to be the other founder of modern science, propagated the experiment for the better understanding of natural phenomena. His methodological proposal was rapidly successful, because many natural phenomena and events are of tremendous complexity, so that their underlying principles cannot be discovered by observation alone. Furthermore, in the course of an experiment, objects can be withdrawn from the real world, examined under controlled conditions and also exposed to specific factors and influences. Hence, effects could be studied which were not previously visible. By thus abstracting from preceding environmental relations, knowledge could be increased and new possibilities of controlling and manipulating objects could be tested. These procedures still form a relevant part of experimental science today. They promote the "invention of new skills" with which it might be possible to reveal the hidden and secret parts of nature. For Bacon, this was the central objective and the path which should be taken by humankind (mankind) in order to rule the universe (Bacon, 1970, p. 415). Science, or more specifically, the acquisition of new knowledge and new products by way of new skills and methods, was in Bacon's eyes also control over nature, which conferred social and political power to those who had this knowledge and those skills at their command.[2]

One principle of the proposed experimental methods was and is to examine the properties of physical objects under controlled conditions. This principle was later also applied to cellular and molecular biology. Following the paradigm of theoretical and methodological reduction of complex phenomena to ever more simple elements, experimental approaches in molecular biology concentrate on the elucidation of molecular mechanisms within cells and the genetic base for these mechanisms. Here again through the exclusion of preceding contextual relationships, objects and phenomena are stripped of seemingly superfluous, unnecessary or undesired complexity, which hinder the identification of the "real nature" of the object or process in question. Thus, contextual relationships themselves are not the object of scientific inquiry. The "loss of meaning," which results from the theoretical and experimental process of abstraction in molecular biology, is substantiated by the difficulties in explaining certain empirical or experimental phenomena using reductionist interpretations. Before some examples for such phenomena will be outlined, a short introduction into the characteristics of genetic engineering techniques is given.

THE CHARACTERISTICS OF GENETIC ALTERATIONS USING GENETIC ENGINEERING TECHNIQUES

Genetic engineering generally involves the excision of individual genes or sections of chromosomes from a particular genome and transfer into a different cell and thus, a different genomic background. In this way it is possible to overcome the barriers which normally limit the arbitrary cross-breeding of organisms of different species. This is precisely the characteristic feature of a species, that is, that only members of a species can be crossed with each other and that it is ordinarily impossible with individuals of another species. Nevertheless, there are exceptions to this rule and hybrids between species are possible, although normally between closely related species (e.g., mules). It is also possible to use genetic engineering to overcome the barriers which limit the exchange of genetic material where bacteria are concerned (e.g., compatibility of groups, differences in the structure of the cell wall, ecological divisions). Since several different changes can be effected using this method within a relatively short period of time, a time-lapse effect is created relative to normal evolutionary processes.

In contrast to the mechanisms which are assumed to form the basis of natural evolution, manipulations performed in the field of genetic engineering make possible (a) practically any number and type of change in the relations between neighbouring genes, that is, in the genetic context of a particular gene: (b) an exchange of genes between different species which in terms of its qualitative and quantitative characteristics go far beyond what is observed within the framework of natural mechanisms; and (c) a reduction in the time required for the development of new species or breeds compared to conventional breeding methods or evolution itself. Finally, it is possible with the help of this range of methods—possibly for the first time in the history of life—to design and synthesize new genetic material, for which older, related predecessors of this genetic material do not necessarily have to exist.

Parameters related to space, time, biology, and natural history which influence the characteristics of individual organisms as well as the way they interact with other organisms, and which have proven themselves to be useful, perhaps even necessary, to life on earth, are therefore altered by genetic engineering techniques (Kollek, 1989, p. 19). Organisms are being created with genetic information and characteristics which they previously did not possess. It is precisely this novelty which is the basis of the potential usefulness of genetic engineered organisms and which makes genetic engineering and its products so interesting for a whole range of possible applications. And it is precisely the novelty outlined above which contains the risk: in the case of deliberate or accidental release of new forms of life, nature which developed of its own accord must cope with this new form of nature which has been invented. Negative ecological consequences could result from these interactions.

CONTROVERSIAL CONCEPTS OF THE RELATIONSHIP BETWEEN GENOTYPE AND PHENOTYPE

In order to understand the relationships between changes in the genetic material induced by the techniques of genetic engineering (recombinant DNA technology) and this risk potential, it is necessary to analyze the factors and procedures which are involved in the generation of this potential. In this perspective, one concept appears to be of special significance: it is the concept of a solely genetically based biology as represented by deterministic concepts. The question is, whether or not such an understanding of organisms is sufficient to explain known phenomena or whether in fact other or additional conditions and factors must be postulated. If the characteristics of (nonhuman) organisms are to a great extent or even entirely based on genetic mechanisms, then one must conclude based on this logic that changes in such characteristics which can be induced through experimental gene transfer will be, in principle, predictable.

The term *gene* was first used in 1909 by the Danish plant breeder W. Johannsen to refer to an element of the heritability of traits. He also used the term *phenotype* for all of the traits which become visible in the life of an individual organism, defining this phenotype as the result of the interaction between inherited traits and the environment. For Johannsen it was particularly important that the phenotype, which he saw as the visible form and spectrum of behavioural patterns influenced in part by the environment, be clearly distinguished from the genotype or the hereditarian type. However, under the influence of the school of thought promoted by Thomas Morgan (prominent U.S. geneticist), he changed this concept two years later, defining the genotype as the sum of all genes leading directly to the realisation of the phenotype (Jahn, Lother, & Senglaub, 1985, p. 472). Apparently however, Johannsen remained divided in his understanding of the mechanisms of heredity of phenotypes and their material bases. Despite the fact that he retracted the concept of the phenotype as being influenced by environmental factors in 1911, he wrote in 1913: “On the one hand we thus have the essence of all genes—the genotype—as the basic constitution of the organism. On the other hand we have the environment, the ‘conditions of living’—and the often extremely complex interaction between the genotype and the environment which result in the actual individual traits of each organism” (Jahn, Löther, & Senglaub, 1985, p. 473).

Thus, from the very beginning of genetics, there were different concepts of the relationships between genotype and phenotype. In the course of time, however, the concepts of traits and genes changed more and more. Today in molecular genetics the concepts of a gene refers to a segment of the DNA which can have regulatory functions or can be translated into a protein. However, in spite of the elucidation of the molecular structure of many chromosome segments, our knowledge of the structure and the biochemical makeup of DNA or of a specific protein does not allow us to infer which biological function a particular protein will have in the cell or how the activity of that protein will affect organs or the interaction between different organisms. Two examples from cellular and molecular biology will be discussed here (in the terms of biochemistry and molecular biology) to illustrate this point.

POSITION EFFECTS

As a result of evolutionary processes, all organisms are genetically related to one another in some specific way. Therefore, some organisms which are not closely related phy-logenetically nonetheless have similar or identical nucleic acid sequences or functional genes. For example, a particular enzyme, an isomerase, can be found in bacteria as well as in yeast cells, insects, and mammals. This enzyme, as found in these various species, has extensive homologies in the amino acid sequences, as well as in its biochemical properties. More careful examination shows however that proteins with identical or similar biochemical properties do not automatically also have similar biological functions. This specific protein, as found in the fruit fly, apparently catalyses the folding of a pigment which is involved in vision, whereas the protein found in mammalian life forms seems to be involved in the regulation of the maturation of immune cells. This means that one enzyme (and the relevant gene) can influence very different biological phenomena with a different ecological relevance, depending on the genetic, cellular or phylogenetic context in which it is found (Fischer et al., 1989; Shieh et al., 1989; Takahashi et al., 1989).

The second example illustrating the contextual relevance of genetic information is from the area of cancer research. The processes which lead to the transformation of a cell into a cancer cell are extremely complex. According to the present status of experimental and theoretical work, certain proteins, the products of so-called oncogenes, are involved in cooperation with other genes in the stepwise transformation of a cell into a cancer cell. In many cases oncogenes are derived from genes which participate in the regulation of growth and differentiation processes. The influence of their gene products on physiological processes in the cell can change under certain circumstances, that is, when (a) the nucleic acid sequence of such DNA segments is modified by natural mechanisms or through genetic engineering manipulations, or (b) more important here, when these sequences are introduced into a different chromosomal environment with the help of such mechanisms. In both cases the specific cell is thus transformed into a premalig-nant or malignant form (Bishop, 1987).

These examples show that the biological effect of the gene is changed when it is introduced into a different chromosomal environment. The biological function of a gene and/or the respective gene product is thus influenced not only by its sequence but also by its specific location within a particular chromosomal and cellular context. Genetic studies on the fruit fly *Drosophila* have shown that there is a concrete relationship between the spatial arrangement of the genetic material and its functional activity. The resulting effects where described Sturtevant, an American geneticist, *deposition effects* in the 1920s (Sinnott, Dunn, & Dobzhansky, 1958, pp. 379-380). The term stands for an empirical concept which enables cytogeneticists to describe phenomena observed on the phenoty-pical level and which have been localized by means of chromosomal studies. The term has also been introduced into molecular genetics but both molecular geneticists and cytogeneticists have been unable to postulate a theoretical explication of this term. To date, there is no comprehensive theory capable of describing the relationships between the functional effect of a gene and its spatial arrangement within the genome. The fact that such position effects exist means as a consequence that the biological significance of a gene is not sufficiently described solely by its nucleic acid sequence, nor the one of a protein by its amino acid sequence, but that rather the relevant topographical data, that is, at least the chromosomal and cellular context, must also be taken into consideration. We must also assume that the time scheme of the activation of a gene can also be influenced by its spatial arrangement within the chromosome. In order to understand the biological (that is, cellular, physiological, ecological) function of a gene, the biochemical description must be complemented by one which considers spatial and temporal factors. In contrast to the amino acid sequence of proteins, these factors are not or, in the case of position effects, only indirectly coded in the DNA. Thus, they can not be deduced from the structure of individual genes.

EPIGENETIC PHENOMENA

Phenotypes, however, are not only influenced by their genes and their chromosomal and cellular context but by their extracellular surroundings and the general environment as well. Although somatic cells—that is those cells which form organs and the different kinds of tissue within an organism—with few exceptions all have the same DNA structure, morphologically they differ extremely. According to the interpretation of cell biology, this morphological variance which gives each type of cell a particular identity, results from the stable interaction between the genome and its direct surroundings (its so-called mi-croenvironment). During cultivation under experimental conditions, cells of differentiated tissues increasingly lose their differentiated functions. The stable inheritance of the differentiated state of a cell thus depends upon the specific organization of the tissue in the environment, that is, on their epigenetic context (Rubin, 1988). (A similar principle holds for embryonal development.) The DNA and its direct surroundings (that is to say the genetic and cellular context) are not changed. They are the same in both cases. The stability or the loss of the differentiated state thus is not influenced by changes in the structure of the genetic material of the cell, but rather by spatial and temporal interactions of the cells.

All these findings show that a reductionist and deterministic approach, according to which DNA is the sole driving force of cellular and developmental processes, is not sufficient to explain the transmission and realization of biological information in an adequate matter nor is it capable of describing fully the phenotype of a cell or an organism.

REDUCTION OF CONTEXTS AND RISK: THE PRICE OF ABSTRACTION

The examples discussed in the previous sections show that the biological significance of genetic information is to a great extent dependent on contexts and that a gene or a gene product may have different biological meanings in different contexts. Ignoring contexts which are defined as not being relevant for a particular area of research is, on the one hand, the prerequisite for the success and efficiency of this strategy and, on the other hand, a prerequisite for the manipulation of the research object. Since these contexts are not the object of laboratory research, the knowledge that is acquired is not relevant or at least not sufficient to controlling these objects under conditions other than those found in the laboratory or in production units. That is, it is not knowledge about the practical conditions of use. The limits of control are thus reached when the objects have been experimentally transformed and are again confronted with complexity and contingency. This is exactly what happens when genetically engineered organisms are created and then put to practical use.

The principle of genetic engineering manipulations is to transfer genes from one organism to another. These genes enter a new genetic context and the products resulting from them enter new cellular and thus also epigenetic and ecological environments. It is not possible to determine beforehand whether these gene products will be of specific significance in these new contexts or whether they will interact with other gene products already present in the cell. In contrast to the possibility of evaluating or predicting the possible behavior of already existing organisms, there is to date very little empirical experience for such predictions with regard to the interactions of genetically altered organisms with the environment. Such interactions cannot be (completely) deduced from the behaviour of such organisms under controlled conditions, since they will be realized only in confrontation with the open environment. This process of interpretation is decisive in determining whether these modified objects will die off, be integrated without causing deleterious effects for their surroundings or whether they will in fact cause problematic interactions, damage, or catastrophies. The efficiency of this strategy of experimental manipulation under controlled conditions is thus tied to the loss of predictability in the environment. Not every genetically engineered modification will increase the risk potential of a specific organism. The problem is however to elucidate which manipulations will have which consequences. Uncertainty and risk are thus the price which must be paid for the total accessibility and control of these living objects in the laboratory.

In the actual practice of risk assessment, it is often assumed that a recombinant organism does not pose a higher risk than the original host organism, plus the specific risk potential of the foreign gene which has been introduced (BMFT, 1986). Such a classification is thus based on the addition of the characteristics of the host organism and those of the transferred gene, the so-called "additive model" (Kollek, 1988a, p. 113, 1988b). According to this view, the characteristics of an organism are seen as the result of the sum of its genes. The addition of a specific gene causes, at most, the addition of the traits coded for by the transferred gene. According to this understanding, the gene is a carrier of information which is independent of the organism or the specific genetic background, that is, the gene is the carrier of context-independent information. Seen from this perspective, one cannot expect that organisms would develop surprising or unknown traits through the transfer of genes with known nucleic acid sequences.

However, although there are cases which can possibly be described in an additive fashion, the examples discussed above show that many biological phenomena cannot be adequately described with this additive model. Such a model can, at best, be used as a base for risk assessment in cases in which complexity and the interconnections of different contexts are limited, that is when only endogenous (intracellular) but not exogenous (extracellular) contexts, such as interactions with other cells or organisms, are involved. This is, for example, the case when manipulated organisms are found in controllable surroundings with a low level of variation, for example, within the physical containment of a biotechnological production unit. Such a perspective becomes problematic however, when complexity and interactions are great (Duerr, 1988, p. 87), such as when transgenic cells or organisms are deliberately or accidentally released into the environment and when the biological effects of the transferred genes unfold in epigenetic and ecological contexts.

The risk of the introduction of experimentally modified organisms thus stems from the fact that no certain prediction can be made as to how information which has been changed on the genetic level will influence levels of higher complexity or, in other words, change the network of intercorrelated functions. An analysis of risks which arise as a result of genetic transfer for the organism itself, but also for the environment with which it interacts, must therefore consider the contextual dependencies of genes, tissues, and organisms as part of the research strategy.

APPROACHING THE MEANING OF CONTEXT[3]

We have seen that the significance of a biological structure is not only the result of the physico-chemical characteristics of its elements, but also of the spatial and temporal relationships to other elements and structures. The context of a gene, a protein, or a cell also influences biological significance. However, we have not yet described in more detail what the concept of context actually means and how it is defined.

The example of embryonal development shows that contexts not only reflect a difference of perspective between the organisational levels of life (chromosome, cell, organ, etc.), but also differences in the establishment of patterns in dependence of space and time. Not only the direct surroundings lend significance to individual parts in the sense of functionalistic interactions. Rather, the continual development of an object in time creates a precondition for its interaction with other objects at specific points in time. Environment and time are thus not only the prerequisite and the framework for the unfolding and development of the inherent potential of a particular object, but also influence the object itself.[4] Within this process of change they produce a specific spatial and temporal structure.

The characteristics of biological objects are thus, at least to a certain extent, relative. They must be described in relationship to the elements of a particular surrounding and on the background of a particular developmental history of the components involved, that is to say, within a particular context. A context, however, does not define the structural and functional interaction of different elements in the sense of a construction plan and it does not contain the information for the structuring of biological (or social) units. Instead, the concept of context is to be understood as one of a "framework which creates significance."[5] A context therefore represents the possibility of interpreting the significance of an object or of an empirical observation in or for a particular situation. In this sense, context is clearly a theoretical concept which does not correspond to a biological (or social) structure, independent of the organisational level of life forms to which it refers, although such structures may be an element of a particular context.

LIMITS OF EXPERIMENTAL KNOWLEDGE

In describing the characteristics of genes it is therefore essential that one consider their context and the existing relationships to other genes and biological interactions. If these are not considered as part of the analysis, false statements about the characteristics of the object studied, in this case a gene, may result. Knowledge which is acquired experimentally is therefore at first relevant to the conditions under which particular phenomena were observed or measured. This means that what is studied in the laboratory under experimental conditions is not nature as such but more precisely specific parts or aspects of nature which can be studied or tested under specific laboratory conditions.

Following this analysis, we realize that the part of nature studied has actually been recreated in an artificial world. What we learn by laboratory experiments does not represent knowledge about nature, but rather knowledge about an experimentally manipulated nature. Scientific statements are thus relevant only for this manipulated nature and for that which can be grasped through scientific methodology and the technical instruments which have been employed. They do not apply to the behaviour of the object of study in the world outside the laboratory. Furthermore, different methods describe the object of study from different perspectives and thus produce different images of reality. The answers we receive are dependent on the questions asked. The methods used are both the megaphone and the hearing aid of the scientific researcher.

This problem can be illustrated with the analogy of a fisherman who uses a net with a mesh of two inches. Because he only catches fish which are larger than two inches in diameter, he could conclude that fish are always larger than two inches. In a similar situation, a scientist would formulate a law of nature. Hans-Peter Duerr (1988, p. 71) has offered a new interpretation of this parable which was originally formulated by the English astrophysicist Sir Arthur Eddington (1939). Duerr relates the parable to our limited ability to recognize nature with scientific, in this case experimental laboratory methods. In his eyes, the net symbolizes the reduction of reality in changes in the quality of perception caused by our scientific point of view.

Theories used as a background for developing questions about nature and the methods that are intended to help in answering these questions have emerged in historical and social contexts. They are thus not neutral in their relationship to reality. Put in a different way, science can be seen as a social undertaking of human beings who act in accordance to specific laws which have developed in a specific historical context and is subject to social change. These laws structure the framework of experience and action by scientists. This structuring is effective with the help of different mechanisms, among them for example specific lines of questioning, special technical instruments, patterns of action and of perception, as well as a specific language and a body of knowledge which accumulates in the course of time. These mechanisms stabilize what Thomas Kuhn has called a paradigm. A paradigm can be defined as a system of laws which determines what kind of questions are acceptable, which strategies of answering these questions are considered scientifically acceptable and which are not. A paradigm defines a framework within which normal science take place (Kuhn, 1967). This also means that there are no singular truth about nature, but that rather than which is observed, is influenced by the questions asked and the structural instruments which are used.

This short view of the history, the prerequisites and the preconditions which have determined the development of science in the past and continue to influence it today, show that we can only expect to have a transient view of natural phenomena and natural objects. It is determined by science and those who do science in two different ways: first through the manipulative interventions which are necessary to carry out an experiment, for example most of the living organisms are dead or in some way manipulated in the course of study, and second through the questions and instruments which have brought to our consciousness exactly this and no other image of nature.

This does not mean that we can not achieve a close approximation of an understanding of reality through systematically searching and asking questions, complemented by historical and practical experience, so that we are able of building instruments and production units which function. The interpretation of science as a creator of instrumental knowledge as it is formulated here does not question its power fulness, its precision, or its successes with regard to the construction of new effects and products. Scientific thought is most successful “where the interactions between different components are weak, where the whole comes close to being understandable as the sum of its parts thought in isolation”, that is, in closed systems where only a limited number of factors have an effect. “Scientific thought becomes problematic however, wherever networks are strong and complexity is great” (Duerr, 1988, p. 87).

EXPERIMENTS IN REALITY

Scientists learn in a laboratory that their objects of study behave according to existing theories. This is not surprising since theories have been formulated on the basis of laboratory experience. Scientists but also many other people tend to apply the principles found under such conditions not only to a specific experimental system, but to consider them to be valid in other contexts. The impression is thus created that knowledge developed in closed systems under controlled conditions, has unlimited validity in open systems as well. This conclusion is neither founded in theoretical considerations, nor always confirmed by practical experience. It becomes particularly significant, when we attempt to predict the results of interventions in the natural environment on the basis of laboratory experiments.

The aim of laboratory experiments is to create conditions which are as constant or controllable as possible. In the environment this is not feasible, the factors of influence (temperatures, humidity, the flow of substances, the variety of specific species, etc.) change constantly. These changes may follow certain regular principles but can hardly be predicted exactly. Rare occurrences (earthquakes, hurricanes, flooding, droughts, volcanic eruptions, etc.) are always possible. Since the characteristics of living organisms in the environment are also defined by their relationships to other living and nonliving elements of the environment, it must be expected that they will behave in relation to these environmental parameters. In particular in the case of genetically engineered organisms not previously found in the environment, exact predictions about their behaviour and thus about specific risk potential cannot be made. This is beyond the theoretical and experimental borders of the laboratory. In the confrontation between primary, evolutionary nature and this secondary, synthetic nature uncertainties and risks emerge, which can no longer be grasped and described with the theories of experimental science (Bon*β*, Hohlfeld, & Kollek, 1989).

Here the limits in the scope and validity of scientific statements and theories are reached, at least in those cases in which they have been formulated predominantly on the basis of laboratory experiments. Today there is intensive work in progress aimed at finding theoretical models for the behaviour of open changing systems capable of development. But although it may be possible to develop such models, which describe actual or real relationships and their dynamics better than those models which are developed on the basis of closed systems, the scope of statements made on the basis of such models is also limited in principle. The reasons for these limits are based on the fact that it is impossible, for theoretical and practical reasons, to predict all possible events and to calculate the probability of their realization.

In contrast we are confronted today with a situation, in which genetically modified organisms are being released into the environment. At present the numbers of different modified organisms which are to be released will be relatively small. The problem of predictability of their behaviour in the environment will become even more significant when large-scale application of such products takes place in the future. By often failing to explicitly point out the theoretical and practical problems of predictability, scientists mask the experimental nature of such releases and the fact that the knowledge necessary to understand and describe risks can only be won through such experiments. However, release experiments, like any other, can fail. In some cases, the organisms will not be able to establish themselves in the environment, in others they may cause irreversible and large-scale damage. It is questionable whether such experiments will be reversible in every case, that is in other words, whether the consequences of scientific curiosity will themselves be reversible. In contrast to chemical substances, these laboratory products can reproduce and change further in the environment. Since the outcome of such releases into the environment cannot be exactly predicted, they are in fact experiments in the environment and with the environment (Krohn & Weyer, 1989).

CONCLUSIONS

By deliberately (or accidentally) releasing laboratory products into the environment, experimental science leaves the room in which it is, as result of its own experience, capable of making valid statements and reliable predictions. Even after consulting ecolo-gists, population biologists, and other scientific disciplines, which contribute to the contemporary understanding of real world biological phenomena, it is difficult to legitimate such unreliable and risky experiments on the bases of the goals of scientific research alone. Therefore, they are often declared to be the application of reliable knowledge in the pursuit of goals, the benefits or necessity of which it is hard to doubt. In connection with the deliberate release of genetically manipulated organisms the main goals named are: contributions for the solution of the problem of hunger worldwide, and the problem of environmental pollution.

But such experiments in the environment are not only about solutions for important global problems. Rather, they are also about specific interests of scientific research and the broadening of the sphere of activity and influence of science. Scientific experts are supposed to be the ones with the power to define which are the adequate strategies for solving social and political problems. In this process, these global problems are defined according to well-known patterns, so that the application of genetic engineering methods appears essential. The problems themselves are defined in such a way that only the desired methods appear applicable. In this way, scientists hold fast to the second cartesian rule according to which, "one should only deal with such objects, for which our power of knowledge clearly is sufficient to produce reliable and indubitable knowledge about their nature" (Descartes, 1972, p. 5). By proceeding in this fashion, science confronts society with risks and dangers which society has a right to reject. This is not a question of a limitation of the right to freedom of research, but rather a question of the limits of experimental science and its statements about reality, about the limits of science itself.

Several feminist scientists have drawn our attention to these limits of scientific knowledge. They have analysed the consequences which result from the lack of self-reflection within science and the application of additive models as a basis for describing human nature. For example, in her study on women, feminism and biology Lynda Birke criticises that the social phenomenon of "male dominance" is ascribed to hormone levels and therefore reduced to a simple biological cause. She points out that there is no scientific evidence for the assumption that biology and environmental influences can simply be added to each other and she rejects the hypothesis that we can thus find out about the biological base of human nature by varying the superstructure. She continues: "Such additive models of human nature are common, but they are fundamentally flawed in one major respect: they do not readily allow for the possibility that the biology itself might be influenced by the superstructure. That such two-way influences can indeed operate is part of the argument proposed against the additive model" (Birke, 1986, p. 44).

According to Birke's analysis, the existence of women's subordination is likely to be seen as the product of invariable biology. Implicit in this is the idea that biology is somehow primary and that on to this the accretions of the social and cultural context can be added. "'Gender', according to this additive view, emerges first from the action of biological factors, be they genes or hormones or whatever; and second from the actions of various social factors, such as learning about gender-differentiated behavior" (Birke, 1986, pp. 53, 54). The problem with the additive model is that it ignores other factors of influence, like parental and social expectations and the interactions with the environment, which occur at all stages of development and provoke new patterns of interaction.

By comparing Birke's analysis with the one on the risks of genetic engineering presented in this article, important parallels become visible. Although both perspectives recognize the relevance of biology, they explicitly reject biological determinism (Birke, 1986, p. 54) and oppose the concept of a linear relationship between genotype (biochemistry) and phenotype (behaviour). These parallels indicate that there is an intimate correlation between those concepts, which are used to describe the nature of non-human organisms, and those describing human nature. In order to elucidate the "secret patriarchal substance" (Ruebsamen, 1983) of scientific conceptualizations of nature, it is therefore necessary to focus on the analysis of methodological approach to nature and the deductions founded on this basis.

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ENDNOTES

1. For a detailed description of the Cartesian ideas and their historical context, see the work of Carolyn Merchant (Merchant, 1980, pp. 192–215). A psychoanalytic analysis of the Cartesian

masculinization of thought was done by Susan Bardo (Bardo, 1986, 439–456).

2. For a detailed analysis of Baconian thought and politics see the work of Evelyn Fox Keller (Fox Keller, 1986).

3. The idea of applying the concept of contextualism to the analysis of molecular genetics originates in my practical experience in molecular genetics. The theoreticcal explication was done in cooperation with my colleagues Rainer Hohlfeld and Wolfgang Bon/3.

(Bonβ, *Hohlfeld, & Kollek,* 1989). The work of Gregory Bateson helped us to specify our thoughts (Bate-son, 1983).

4. This aspect was also pointed out by Lynda Birke for the development of humans (Birke, 1986, p. 53). It is discussed in more detail in the final section of this article.

5. In linguistics, the term *context* means the relation ships of a word or a sentence (grammatical context), or the situation, in which a sentence is used and under stood (pragmatic context).

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