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Darwin, Lamarck and the Evolution of Science and Culture

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Summary: What is being discribed as differences between organic and cultural evolution (for example that one is Darwinian, the other, Lamarckian in character) depends on the implicit agreements made on what are analogue issues in culture and life. A special consequence of the definitions used is that opposite causal mechanisms are attributed. The development of empirical scientific theories is seen as an internal adaptation to external data. Organic evolution, however, is seen as an external selection of internal modifications. Seeing science as a special cognitive tool in the sense of evolutionary epistemology (EE) which then has to evolve according to the same principles as evolution of organic tools does, would require some notional realignments in order to level the established organismic/cultural dichotomy. Central to the approach used here is the notion of reality and adaptation. The EE declares that human categories of perception and thinking (space, time, object, causality etc.) result from evolutionary adaptation to the independent structures of an ontological reality (Campbell: "natural-selection-epistemology"). Here a "Constructivist evolutionary epistemology" (CEE) is proposed which goes one step further and considers also the category of reality itself to be a special mental concept acquired phylogenetically to immunize proven ideas under the label of "reality". According to the CEE, the evaluation criteria for strategies and theories are the consistency with the previously and phylogenetically acquired organic and mental structures, rather than the adaptation to external data. A similar view can also be held in organic evolution where the various metabolic processes and higher strategies modify the external data according to their previously established own requirements rather than changing those requirements in adaptation to external data. Thus cognitive and scientific as well as organic evolution is an enterprise of conquest rather than of discovery and reality will lose its role as a universal legislator and evaluator. The CEE implements this thought, by considering all regularities perceived and the laws of nature derived from them as invariants of mental or sensory operators. The extension of human sense organs by means of physical measurement operators leads to the completion of classical physics if the experimental and the inborn cognitive operators commute. Otherwise non-classical (i.e. "non-human") approaches are required such as quantum mechanics, which are based on the invariants brought about experimentally. As the set of possible experimental facilities (and therefore of new invariants) is not closed it follows that evolution of science will not end in a definitive "theory of everything" but in basically endless co-evolution between experiments and their theoretical interpretations. The same applies to organic evolution which can be considered as co-evolution between genomic structures and their interpretation by the epigenetic system which itself is subject to genomic modifications. This may lead to non-stable recursive processes described here as non- linear genetics. Some general evolutionary strategies and principles are discussed with a view to being applicable in organic evolution as well as in cultural and social evolution. Special consideration is given to the view that the need to master the physical world (mainly being done by scientific efforts) may be superseded in the long run by the need to master our social environment.

Introduction

Seldom has a scientific idea survived with greater persistence in general and learned education than that of the Lamarckian character of cultural evolution, in opposition to organic evolution which according to everything one reads from empirical sciences is Darwinian:

- S.J. Gould (1979): "Cultural evolution has progressed at rates that Darwinian processes cannot begin to approach. Darwinian evolution continues in Homo Sapiens, but at rates too slow that it has no longer much impact on our history. This crux in the Earth's history has been reached because Lamarckian processes have finally been unleashed upon it. Human cultural evolution, in strong opposition to our biological history, is Lamarckian in character. What we learn in one generation, we transmit directly by teaching and writing. Acquired characters are inherited in technology and culture. Lamarckian evolution is rapid and accumulative. It explains the cardinal difference between our past, purely biological mode of change, and our current, maddening acceleration towards something new and liberating - or towards the abyss."

- P. Medawar (1988): "Cultural Lamarckism has a great inherent plausibility, because social evolution is so obviously Lamarckian in character - we learn generation by generation and can propagate our learning to the next generation."

But what, exactly, does Lamarckian evolution mean? To speak in terms of inheritance of acquired characters is not very enlightening. All characters have once been acquired, either genetically, i.e. by genetic mutations, or culturally, i.e. by means of learning; and all characters are inherited, either genetically or culturally. So, the inheritance of acquired characters can hardly specify a relevant difference between Lamarckian and Darwinian evolution. What we really have in mind when comparing cultural and organic evolution is something different: knowledge as a particular subject of cultural evolution is seen as something which is brought about by means of procedures which usually guarantee a certain usefulness, whereas the value of genetic mutations is entirely a matter of chance. Let us try to transfer this into a definition which is general enough to be applicable in the organic/genetic context as well as in cultural:

- An evolution (of what ever) shall be called Darwinian if it follows the principle of trial and error, i.e. if it starts from accidental modifications which subsequently will be selected (or more generally: evaluated or interpreted) according to independent criteria.

- An evolution shall be called Lamarckian if a calculus is applied by means of which modifications can be produced which will be considerably more successful than purely accidental modifications - a calculus for example which makes it possible to meet given (external) requirements in a target oriented manner such as a genetic reproduction of "acquired characters" i.e. of any proven phenotypic modification brought about in a living organism during its own lifetime; or a theory which will allow reasonable planning rather than Darwinian trial and error.

According to these definitions we have to distinguish clearly between the genesis of modifications which can be Darwinian or Lamarckian, and their subsequent dissemination which has nothing to do with Darwin or Lamarck. That "what we learn in one generation, we transmit directly by teaching and writing" as Gould said, does not qualify cultural evolution as Lamarckian. Also genetic achievements (i.e. modifications which passed selection) will be transmitted directly to the next generation. A difference, of course, is in speed and in the potential number of individuals involved. In cultural evolution, and particularly in the times of telecommunication, it is possible to communicate within seconds with everyone, whereas genetic information can be exchanged only between mates (leaving horizontal gene transfer aside), and to "inform" the entire population on individual genes takes many generations. So, cultural evolution proceeds indeed very much faster than genetic evolution does, but this is due to the fact that genetic and cultural knowledge use different ways of disseminating their modifications and has nothing to do with the way in which the modifications concerned have been brought about.

A semantic confusion

What, then, are the differences between the genetic and cultural techniques of generating innovations or changes, and how significant are they?

The transformation from the genome into the phenotype is done by what since Waddington (1957) and Riedl (1975) is called the epigenetic system, meaning, briefly, the totality of the developmental processes involved. The epigenetic system is something highly specific. It would reject not only any alien genome (interbreeding between species is impossible) but also inappropriate (i.e. lethal) mutations. So, the epigenetic system has two functions: on the one hand, it translates the genotype into the phenotype according to very specific rules (a Lamarckian process, so to say), and on the other hand it selects the purely accidental mutations according to their appropriateness for the various levels of the developmental process - a Darwinian mechanism, as long as the mutations do not change the epigenetic system itself.

Preselection of inappropriate input data is not reserved for organic evolution. In a "cultural" situation which we cannot master with available tools, a lot of ideas will cross our mind. Some of them we will identify immediately as unrealistic. Others will turn out to be inappropriate only after careful comparison with the theories we know. Only a few will pass all our checks (and, in the case given, also those of other persons). These we will use to approach the problem given. H.A. Simon (1983, p. 40) said: "According to the behavioural theory, rational choice may require a great deal of selective search in order to discover adaptive response. The simplest, most primitive search processes require that possible responses be first generated and then tested for appropriateness. The generator/test mechanism is the direct analogue, in the behavioural theory of rationality, of the variation/selection mechanism of the Darwinian theory. Just as in biological evolution we have variation to produce new organisms, so in the behavioral theory of human rationality we have some kind of generations of alternatives - some kind of combinatorial processes that can take simple ideas and put them together in new ways. And similarly, just as in the biological theory of evolution the mechanism of natural selection weeds out poorly adapted variants, so in human thinking the testing process rejects ideas other than those which contribute to solving the problem that is being addressed".

There are further parallels between genetic and cultural evolution. Whenever new ideas or theories were the outcome of our own fantasy or thinking, they would correspond in biology to mutated genes. The critical evaluation of these ideas in the light of all we know (consistency test) would correspond to the selecting evaluation by the epigenetic system. The evaluation in the light of experiments made in the outside world would correspond to the normal Darwinian selection by the physical biotope concerned. Evaluation in the light of what other people know or believe means natural selection by the social environment (i.e. competition). The result could be called individual (genetic or cultural) learning. If we adopt, however, foreign ideas which usually have the advantage of already having been tested by other persons' experiences and combine them with our own concepts, then this would correspond to the adoption of proven genes within the framework of sexual communication and their subsequent recombination. This we will call social (genetic or cultural) learning. So,

the term individual/social refers to the source of data (Did I learn myself, or did I let others learn for me?), whereas the term genetic/cultural refers to the type of data concerned (Is the result stored in my genes or in my "memes"?). In an exclusively cultural context social contacts and social learning are always cultural, which sometimes prompted people to replace the term "social" by "cultural" (see Callebaut, 1987). Then, however, when drawing the parallel to organic evolution, genetic learning by sexual recombination and reproduction has to be called a cultural phenomenon, which would be against all scientific phrasing practice. All theories, plans or developmental processes have a certain range of competence inside which they act in a well planned, predictable and proven manner - Lamarckian processes according to the definition given. Outside this range, however, they can succeed only according the possibilities of Darwinian trial and error. For the embryogenesis based on a special genome, for example, the competence ends with the production of a viable organisms. Whether, however, a certain organism, once it has been produced, will survive in its physical and social environment or not, is outside the competence of the epigenetic system. Here the only method organic evolution can apply is that of trial and error, (whereas the Lamarckist believes that the developmental process has at least partially the ability to respond also to given external requirements). Something similar applies for culturally acquired theories. Economic and social theories, for example, may tell us what particular budgetary or employment measure will increase inflation, but their competence is not sufficient to predict the outcome of more complex measures in full generality. The consequence is that policy, despite all scientific efforts, is largely a matter of trial and error. So, whether we have to call a modifying process Lamarckian or Darwinian does not so much depend on the process itself but rather on whether we look at the process from inside or outside its competence. The terms Darwinian and Lamarckian, therefore, describe aspects rather than qualities.
If we look at two different processes, one from inside, the other from outside their competencies, than it is evident that we will see different phenomena but these need not reflect possibly existing real differences. It is as if one would compare the physical hardness of two metals, one below and one above the respective melting point. This we have to keep in mind when comparing genetic and cultural evolution: If we speak in terms of theories and knowledge to be transmitted culturally to the next generation, we mean proven and tested theories, i.e. the result of cultural learning, and not the uncontrolled and unproven outcome of fantasy and intuition. These proven and tested theories we have to compare with the results of genetic learning i.e. with the proven genetic modifications which have already shown their ability by producing an organism which can survive and reproduce and, therefore, "will be transmitted to the next generation". Stephen Gould, however, (and others) look at cultural evolution from inside its competence and at genetic evolution from outside, i.e. they compare culturally acquired theories which have already passed all checks with spontaneous genetic mutations which still have to pass all testing. If at all, the latter has to be compared with culture, policy etc. by looking from outside the competence of the theories by means of which we try to guide social development. Then the evolution of culture would be Darwinian, driven by incompetent human action in the same way as organic evolution is driven by "incompetent" mutations. So, to try to distinguish organic and cultural evolution by means of the terms Darwinian and Lamarckian is based upon a kind of semantic confusion.

Cultural and social individuals

The Darwin/Lamarck debate on cultural evolution is largely based on the a priori suggestion that culture is a complete novelty incomparable to anything known in previous stages of evolution. This is no doubt adequate as far as the purely technical aspect is concerned (language and science, of course, are tools which eukaryotes or crocodiles do not have at their disposal) but it may be less adequate if we see the "invention" of culture in the tradition of a series of similar innovations evolution has brought about primarily by developing new forms of communication. The first one was the discovery of genetic or sexual communication. Because of the high specificity of the developmental process, sexual communication requires the existence of species, i.e. sets of individuals being genetically and epigenetically similar enough to be able to interbreed. Genetically distinct species, therefore, can be seen as the outcome of genetic communication. The second one was when eukaryotes "discovered" that they could communicate not only genetically but also physiologically. As this requires the direct physical contact of those involved, it lead to the constitution of physically compact units we call multicellular plants and animals, i.e. of individuals in the proper sense. The third "global change" was when some animals and particularly men found that they can communicate also culturally. This lead to "cultural individuals" in form of knowledge on how to hunt together, of other common useful ideas, and eventually of scientific theories. It also lead to a variety of "social individuals" according to the various kinds of cultural information exchanged: hunting cohorts, groups, parties, companies, scientific communities and any other kind of social organisations. As cultural communication is mainly based on remote sense interaction which does not need physical contacts, social individuals are not necessarily disjunctive, i.e. physical individuals can be - at the same time - members in several social individuals. (This, I think, is the very difference between organic and social individuals). A fourth level is opened by the social individuals themselves when communicating by means of the various economic, political and cultural mechanisms constituting what we usually call a society. In a later section we will defend the idea that in general a functionally comprehensible definition of individuals or units is possible only by means of a constituting interaction.

Non-adaptive evolution of cognition

Also Cultural "individuals" can communicate. Scientific theories, for example, interact in academic debates and perform by this scientific disciplines which evolve, like biological species, more or less independently from each other. A significant difference, however, is seen between the development of empirical scientific theories and organic evolution: Science is said to be teleological in character, converging (though in sometimes rather roundabout ways) towards the hopeful end physicists call the "theory of everything", whereas organic evolution obviously has no specific focus towards which all species will converge. Another difference in the way we look at organic and cognitive evolution was described by Piaget (1975). We see organic evolution in terms of autonomous internal modifications (mutation, recombination etc.) to which the external world reacts by means of selection mechanisms, whereas in cognitive evolution we speak in terms of an autonomously existing and changing world to which intelligent beings respond by means of formation of theories and learning. So, the attribution of actio and reactio is opposite in the theories we use to describe organic and cognitive evolution.

Recent research in cognitive science and related epistemological approaches may give reason to see these differences in a somewhat different light. The so-called constructivist evolutionary epistemology (CEE, Diettrich 1991) considers all regularities perceived and the laws of nature derived from them as invariants of mental operators. This is similar to modern physics which defines the properties of subjects as invariants of measuring operators and which accepts theoretical terms only when being "operationalisable", i.e. if they can be defined as invariants of special operators. Physicists have taken this position after it turned out that the "failure" of classical physics was mainly due to the use of non operationalisable theoretical terms. The CEE generalises this by saying that also obeservational terms owe their existence to an operationalisation, not, of course, by experimental facilities but by the mental operators comprised in the sense organs. This means that even the most simple laws of nature, based on nothing but direct observation are specific to human beings. This will apply, for example, also for the law of the conservation of energy which can be derived from the homogeneity of time and therefore will depend on the phylogenetically evolved mental mechanisms which define the metric of time perception according to their special physico-chemical implementation. The mental metric generator is also responsible for the causal relationships we articulate: Prior to all further theories, the hypothesis that lightning is the cause of thunder (and not the other way round) is based on nothing but the statement that the time between lightning and the next clap of thunder is usually much shorter and varies less than the time between thunder and the following lightning - a statement we cannot make without being provided with a given time-metric (Diettrich 1989).

Reality, though the most evident notion of all our life, is not operationalisable. To expect from reality to exist with all its structures independent of any human action, i.e. to be invariant of any thinkable operator, would deprive it of all specificity it needs to be a non-trivial category and which can result only from the fact that it would be invariant of certain but not all operators. (Only the trivial unity notion is invariant under all operations). The only way to define a kind of reasonable reality is to refer only to actions and operations done up to now. Then reality is a synonym for all the regularities brought about by the mental operators and for all we have concluded from all our doing. In order to preserve these products as the stable and therefore reliable elements for further conclusions and theories, evolution has charged them with a high "cognitive burden" comparable to the so-called genetic burden (Riedl 1975) exempting basic organic structures from further evolutionary modifications. This burden is implemented by the inborn idea that the basic elements of what we see are determined by the structure of an objective and independent reality which, by definition, cannot be changed - or in other words: what we call knowledge is declared as knowledge on reality, and as long as we consider a certain piece of knowledge to reflect the structure of reality, it would contradict our understanding of reality to change it.

Also mathematical regularities and the laws of logic are not universal. Rather they have to be seen as invariants of certain human mental operators. If these mathematical and perceptual operators are phylogenetic homologa and therefore have similar structures, we have the possibility of explaining why mathematical methods are so successful in extrapolating experimental data (i.e. why induction works) (Diettrich, 1991) or, as Davies (1990a) put it, why the universe is algorithmically compressible. This does not mean that an in-depth analysis of the brain's hard- and soft-ware would be the very clue for any physical law men ever could find. This applies only for those laws based on simple observations of the unaided sense organs such as the laws of classical mechanics. The laws "found" in higher physics, however, had evolved furthermore as invariants of the experimental facilities applied and thus cannot be derived alone from nor are they determined by the given functional structure of the brain. They cannot even be explained in classical terms if the experimental facilities concerned do not "commute" (as physicists would say) with the operators represented by human sense organs. Experimental results can be described coherently only in terms of the invariants of operators with whom they may commute. This is the reason why quantum mechanics or the theory of relativity exceed the framework of classical description.

Non-adaptive and non-teleological evolution of science

The anthropic character of the regularities we perceive and therefore of what we call the laws of nature excludes the possibility that our scientific efforts will converge towards a "theory of everything" describing the "true" structures of an independent reality. The only thing we may

achieve are better and better tools for solving our physical problems. Yet, similar to organic tools of animals, they cannot be evaluated in terms of a context free truth-value.
In this context it is helpful to consider theories under two different aspects: function and structure.

- Theories in the **functional** sense: Lorenz (1971 p. 231-262) and Popper (1973 p. 164) have suggested enlarging the notion of theory towards all kinds of problem solving instruments. This would comprise physical theories in the proper sense in so far as they help us to master technical problems and to control physical nature; the inborn categories of space and time we use to interpret perceptions and to coordinate mechanical activities; limbs as instruments for locomotion; biological species as an instrument of "life" to meet the particular requirements of a special biotope; social communication and social bodies arising from it as a tool to meet the requirements of a wider social environment. All these various kinds of theories we will call theories in the broader sense, as opposed to rationally generated theories in the usual sense such as physical theories.

- A theory in the **structural** sense is considered to be a picture, an image or a mapping of an object, of an area or, more generally, of a section of nature. It is understood that the structure of the theory and the structure of the object described are partially isomorphic.

The legitimation of science as an enterprise to discover the structures of the world in order to master physical problems is based on the assumption that functional and structural theories are equivalent in the sense that a functional theory will succeed only if it is structurally "true", and that a structurally true theory per se will have functional merits. This is an allegation based on two suggestions: (1) that a problem would determine the methods of its solution, i.e. that functional adaptation would determine the structures and procedures by means of which adaptation will be achieved and (2) that the structure of a theory in the broader sense will determine its functional qualities. Both are hard to defend: (1a) Horses and snakes, for example, though they may have developed in a similar physical environment, have entirely different organs of locomotion which have no structural element in common. So, the hooves of horses can not be considered, as suggested by Lorenz (1966), to be a sort of image of the steppe-land on which they live. Another example is the idea that the structure of reality would determine the regularities we perceive and which we condense to the laws of nature, i.e. that the structure of what we see has something to do with the structure of nature. This argument raised hopes of sending some very elementary messages on typical human and terrestrial issues by means of a rocket into space. It was assumed that a universal reality would bring about at least similar ways of seeing the world, independent of whatever kind of extraterrestrial intelligence would be involved, so that, at least in principle, a rudimentary communication with beings from other planets would be possible. This view is indefensible as the category of reality itself, as we have seen, is anthropic. (2a) As to the functional qualities of a structural theory: structural theories cannot represent "objective" problem solutions, helpful for everyone confronted with the problem, as there are no objective problems which would require objective theories. Problems are nothing but special problems of special individuals in special situations. All human striving for a better life can be reduced to achieving certain perceptions and avoiding others. This is what our special problems are and this is why theories can succeed in providing us with "better" perceptions only if they deal with the relations between those perceptions which are invariants of the human cognitive apparatus as they do in empirical sciences (here, of course, they do remarkably well!). Objective theories, however, based on the structure of an external reality (what ever that would mean) are empirically unverifiable. So they are entirely irrelevant and useless - and so are all efforts to find them. In other words: Science must be anthropic. Otherwise it would deal with matters with which men have no relation. So, man-made science has functional qualities only for man-like individuals.

One of the earlier notional splittings in cognitive evolution is that into *observational* and *theoretical* terms. Perceptions can be considered as kinds of theories unconsciously performed in terms of the invariants of cognitive operators, by means of which we structuralise the sensational input - in the same sense as we apply consciously constructed physical theories in order to structure the relations of perceptions. The so-called observational terms which describe what we see directly, and the so-called theoretical terms which comprise special interpretations, are both theories in so far as they are "man-made". The only difference is that observational terms have developed phylogenetically in the unconscious parts of the human brain, whereas theoretical terms are the outcome of conscious and rational efforts. Then, the old dichotomy of observational and theoretical terms is reduced to a rather secondary difference. Nevertheless observational terms remain privileged as the basic elements of any higher theories in so far as we can modify theories according to observational data, but we cannot modify the genetically fixed mental operators and their invariants according to the requirements of special situations, though it may well be profitable. (Future high-speed astronauts e.g. may deplore not having the inborn ability to identify lorentz-invariants, and a sound engineer might be interested in the ability to perceive spectral acoustic data explicitly and not only in the form of tone colour).

If we base empirical theories on observations, as we actually do, and if observations are theories as well, then the evolution of science is an entirely internal matter between theories. Whatever we call the structures of reality, it must be comprised in the more elementary theories upon which we found higher theories. Reality, so to say, is the outcome of its own history. This will allow us to see the realist's main argument in another light: the basic experience of all men is that our perception contains regularities we cannot influence. So, they must be objective, the realist infers, and hence it is legitimate to try to condense them to the laws of an objective world. Here, we concede that we have indeed no means to influence the regularities perceived nor can we alter what we call the laws of nature - but only so far as the present is concerned. In the past, as we have seen, we contributed well to the shape and form of the regularities we identify in sofar as the generating mental operators are the outcome of an independent evolution (or co-evolution). For example our phylogenetic ancestors explicitly designed the law of energy conservation when they decided upon which type of physical mechanism should emulate the mental clock defining the metric of time. The regularities, therefore, which men perceive and condense to general laws represent nothing but their own previous history. So when arguing against reality as an independent institution it is not intended to say that we could ignore traffic lights or concrete walls as many people would suspect. It just refers to reality as a universal legislator being supposed to give laws which are relevant for everybody.

Though science does not converge towards a definitive version such as the theory of everything, it is not completely arbitrary as suspected by Davies (1990b): "Why bother with science at all when an anthropic explanation for almost any feature of the world can be cooked up?" Science has to describe the (given) invariants of the phylogenetically defined sense organs, i.e. the regularities we perceive directly (here we cannot intervene) and the (unpredictable) invariants of the scientifically established experimental facilities. Particularly the latter are mainly chosen with a view to questions science itself has raised. If they happen to have new invariants that the unaided sense organs do not have (i.e. if there are regularities not perceived before), the theories have to be changed accordingly. Thus between the theories we design to meet new experiences and the experiments we plan according to the advice of new theories there is the same principally endless co-evolution as between genetic modifications in organic evolution which may have to be met by new applications and applications which, in turn, constitute new adaptive forces for new genetic modifications. (Birds pecking corn would die out if their small bill grew genetically an unsuitable size - unless they learn to use their nebs, say, to crack nuts. From then on modifications will be evaluated and selected according to their nut-cracking power). The boundary conditions for the further development of science are defined by the entire evolution we have passed through from the organic beginnings up to the cognitive decisions of our early ancestors and to what we call the established scientific knowledge. These boundary conditions, which a special element in our cognitive evolution told us to see as the outcome of the "structure of the world", do not determine future theories, but they will - in contrast to what Davies apprehends - prevent them from being entirely arbitrary. So, we cannot expect to find a theory of everything in physics as "everything" is an open set which we ourselves fill up again and again, and nor is teleology a reasonable concept in science. The evolution of cognition, theories and science with all its openness and unpredictability perfectly mirrors organic evolution. It is evident that evolution will not converge towards a definitive species of absolute fitness, the pride of creation so to say. New evolutionary achievements will provoke emigration into new appropriate niches which at the same time would also comprise new risks and requirements to be met by new adaptive efforts and so on. Nor will be there a definitive physical theory, the pride of science so to say, as each new theory will provoke new applications and experiments with unknown outcome which may require new theoretical efforts.

Non-linear genetics

Another example for co-evolution between a structure and its interpretation, i.e. between a structure and for what this structure will be used, is the co-evolution between genomic structures and the epigenetic system expressing them into the phenotype concerned. It is classically held in biology that the genotype is a sort of "blueprint" which carries all relevant information for the construction of the organism. Actually, however, - and this is an increasingly noteworthy idea in biology (Katz 1982) - the genotype does not define or determine the phenotype in the sense that a purely mathematical analysis of genomic structures will allow us to construct the phenotype. "An essential ideological component of the genetic approach to development is the view that development follows a 'program' and that this program is embodied in the genes. But this view is rooted in a semantic confusion about the concept of 'program'." (J.C. Gerhart et al., 1982). The genome is not the blueprint we simply have to read and understand in order to see what the organism will look like. It is only the epigenetic system (ES) - mainly comprised in the zygote - which performs the gene expression and which, together with the genome, will determine the structure of the phenotype. A consequence is that organic reproduction has to be considered as a cyclic process which can be modified in principle at any stage: at the genomic stage where we can intervene by means of artificial mutations as well as at the epigenetic stage. So, further to classical gene technology it must be possible as well (at least in principle) to carry out epigene technology. Nature itself does so when genomic mutations modify not only the phenotype but also the ES involved. So the EE plays a double role which leads to another interesting consequence: on the one hand the ES is the instance that regulates the gene expression, or that "interprets" genomic into phenotypic structures. On the other hand the ES itself is the outcome of genes which have been expressed by means of the ES of the parental organism. So changes in the ES may occur not only due to genomic modifications but also due to a modified interpretation of the genome according to the ES's own predecessor. Switching a special mutation on and then switching it back in the daughter organism would lead to the

original phenotype only if the ES was not affected. Otherwise the genome, though again in the previous state, will be differently expressed which in turn may lead to still another ES in the third generation, and so on. This relation meets the mathematical criterion for nonstable recursive processes. This means that long-term evolutionary processes can develop their own dynamic which does not need to depend on consecutive genomic mutations or environmental changes. (It might be difficult to identify such shifts empirically as they have to be separated from the effects of sexual recombination and mutation). Thus it is possible (Wagner, 1992) to accommodate cases of "cortical" inheritance of ciliates and the apparent disjunction between morphological and biochemical evolution in Tetrahymnea in a natural way (Williams, 1984). That there is indeed an evolution which is manifested epigenetically rather than genetically can be deduced from a work on the homology concept in biology (Wagner, 1989). Using the development and variation of pectoral fin hooks in blenniid fish as a model, it is shown that cyclical ontogenetic networks can lead to epigenetically closed aggregates of traits which together can constitute semiautonomous and replicable units of phenotype or homolog.
This concept of what we call non-linear genetics can be formalized as follows:

Let G_i be the genome of the wildtype of the species i. ES_i be the ES and P_i the phenotype of this species. The expression

$$G_i\,(ES_{i(0)}) = P_{i(1)}\,,\,ES_{i(1)}$$

has to be read as follows: The genome G acts as operator upon the ES (left side) and by this generates a phenotype P and a new ES (right side). This process describes an identical biological reproduction if $ES_{i(0)}$ is eigenvector of G_i , i.e. if $ES_{i(0)} = ES_{i(1)}$. Accordingly, P_i shall be called Eigenphenotype.
If the primary ES_i is not an eigenvector of the genome, then this will lead in the following generations to a sequence $ES_{i(k)}$ with k = 1, 2, 3,... . Accordingly there will also be different phenotypes P_i. The sequence will break off if the distance to the original constitution will become so large that the triple genome, ES and phenotype no longer represents a reproducible unit. From a certain k' on we will have therefore,

$$G_{i(k')}\,(ES_{i(k')}) = 0.$$

The lineage found a kind of natural death which is not based upon external selection. However, it may also be possible that, from a certain k^* on, $ES_{i(k*)}$ will be a (different) eigenvektor of the genome. Then we will again have stability.
What are the possible consequences of a genetic mutation from G_i to G'_i ?

1. ES_i is eigenvector not only of G_i but also of $G'_{i,}$ but to a different eigenvalue P_i. This represents the normal case of an inheritable mutation leading to a stable phenotypic variant. A mutation from G'_i back to G_i will also lead back to the original phenotype, i.e., as long as mutations do not affect the ES, they will determine phenotypic modifications.

2. ES_i is eigenvector of G'_i but to the old eigenvalue P_i (P, then, is degenerated). This would correspond to what since Kimura (1982) is called a neutral mutation, i.e. a mutation without phenotypic effect.

3. ES_i is eigenvector of G'_i to the eigenvalue 0: $G'_i\,(E_i) = 0$, d.h. the mutation is lethal. This is what we called the natural death of a lineage

4. ES_i is not eigenvector of G'_i. Then we will get the above mentioned lineage which will either find a lethal end or will converge towards a new eigenvector ES'_i and by this towards stability. In this case a mutation back from G'_i to G_i will not lead to the old phenotype. Mutations are irreversible as to their effects if epigenetic modifications are involved.

From the formal point of view, non-linear genetics of the kind reported here represent an attempt towards the integration of development with evolution, a requirement which can be traced back even to Darwin who recognised that development provides information on evolutionary history. It was realised all the more in later times that there is a crucial mechanistic connection, in that development translates genotype into phenotype. Nevertheless we have not yet managed to build a theory of evolution that satisfactorily incorporates development as well as genetics. Also, non-linear genetics as suggested here can hardly be seen as what W. Arthur (1989) called a theory of the evolution of development as it does not do much more than assume that the interplay between genome and epigenetic system is part of a recursive process which does not necessarily lead to identical reproduction, either of the epigenetic system itself or of the phenotype. For the time being, there is no theory at the molecular level which could provide a model for long-term evolution based on non-stationary recursive mechanisms. On the other hand, thinking in that direction may favour seeing organismic life histories under the aspect of morphogenesis (generating the distinct morphologies of species, particularly if non-linear genetics provides evolution with a kind of "developmental" component) rather than of heredity (stabilising these processes from generation to generation) as suggested by Goodwin (1988).
Something very similar to non-linear genetics can be seen in social development. It goes without saying that there is nothing in a society which is not based on individuals and their traits, though human traits and individual action cannot be said to determine social structures (Hayek, Popper). It is only the social environment acting as a sort of social epigenetic system that evaluates individual behaviour and translates it into the "societal phenotype". So, the same trait can have entirely different effects depending on the social context. Individual egoism for example will generally be destructive in family-like, so-called closed societies, whereas it may well contribute to competition based prosperity in large, open societies. In analogy to non-linear genetic phenomena, individual action can also modify the mechanisms of societal expression and thus can change the societal phenotype independent from "mutations" in the pattern of individual behaviour. In former times, for example, an individual opinion had to pass many intermediate links before it could establish itself as part of public opinion. Nowadays, however, man-made telecommunication techniques enable an opinion to be presented in one step to nearly everyone. This means altered processes of cultural pre-selection and therefore of societal reproduction.

Non-linear phenomena can be seen also in the development of science. The established sciences with all their experimental and theoretical tools are, so to say, the "epigenetic system" which transforms observations into the currently ruling theories. These theories (similar to organic phenotypes) may change according to new empirical data (mutations, so to say), but also according to paradigmatic or "epigenetic" changes which would cause different conclusions from the same known data. A certain very high Doppler-shift in the spectrum of a moving light source, for example, which was interpreted in times of classical physics as an indicator for a speed greater than c, is now seen, according to the relativistic Doppler-effect, as the outcome of a speed below c. As we will see below in more detail, experiments we do on behalf of scientific demands, and scientific theories we design on grounds of the experimental results achieved proceed in the same kind of autonomous co-evolution as genomic and epigenetic structures do.

Non-adaptive organic evolution

The CEE speaks of the "home-made" character of the regularities we perceive and condense to useful tools of life management - contrary to classical realism for which the regularities are representations of real and external structures. The latter is a direct analogy to classical Darwinism: the special structural and functional features species have developed in order to meet the selection criteria of their environment are seen as "pictures" of the environment. Lorenz (1966) for example described the matching between organic and environmental structures by saying that the hoof of the horse "represents" or "copies" the soil of the steppe-land on which they live. Yet, environmental conditions are not absolute in the sense that they require responses from any organism. Changing external temperatures, for example, require homeostatic measures of warm-blooded mammals but nothing equivalent for reptiles. Thus, to a great extend it is the organism itself which, in the course of its phylogeny, defines the criteria it has to meet further on. Once these criteria are defined, the individual has to adapt external data to internal conditions, for example by internal homeostatic measures in order to realise the temperature required or by simple locomotion until a more appropriate environment has been found, or by selecting the eco-niche within a local habitat, i.e. by acting in the wider sense. But it does not usually change the established elementary internal mechanisms according to changing external data. This is close to what Waddington wrote (1959): "Animals are usually surrounded by a much wider range of environmental conditions than they are willing to inhabit. They live in a highly heterogeneous 'ambience', from which they themselves select the particular habitat in which their life will be passed. Thus the animal by its behaviour contributes in a most important way to determining the nature and intensity of selective pressures which will be exerted on it. Natural selection is very far from being as external a force as the conventional picture might lead us to believe". The most advanced form of acting is the active modification of the environment according to own requirements. This goes from birds' nest constructing to ants' plant-louse farming and eventually to technologies which enable us to live even in outer space. At least in principle and from the technical point of view, we are able to render ourselves nearly completely independent from the physical data of our environment.

So we can conclude: an external world, however defined, determines neither scientific knowledge nor organic "knowledge" in the form of well adapted structures. The boundary conditions for further evolution which we are accustomed to describe in terms of the structure of nature are rather defined by what evolution itself has brought about up to now, i.e. the evaluation criteria for strategies and theories are consistency with the previously and phylogenetically acquired organic and mental structures, rather than adaptation to external data - and in organic evolution: the various metabolic processes and higher strategies modify the external data according to their previously established proper requirements rather than adapt change their requirements to external data. Thus cognitive as well organic evolution is an enterprise of conquest rather than of discovery. This does not mean that adaptation as experienced in daily life or described in Darwinian theories does not occur. It only suggests that adaptation has to be interpreted as a process of exploring the various possibilities reduced or enlarged by all the previous developments, rather than as a process of coping with the predefined structures of what we call reality.

What we have explained here is, when described in the terms Piaget (1974) used in the context of behaviour, a world of assimilation without accommodation. Assimilation means to modify or use external data in order to meet internal needs. Accommodation means to modify these needs in order to be met more easily. Accommodation, indeed, does not occur at the elementary level where the basic structures of the organism are defined which then are (genetically) fixed and exempted from further evolution. Basic structures are subject to what Riedl (1975) called the genetic burden. As to this level, the organism can survive only by means of assimilation. But accommodation may well occur at the higher levels which still have some degrees of freedom, particularly at the level of assimilation itself. This means that the organism has the possibility of improving the strategies of assimilation. At the behavioural level, acting with a view to better exploiting the environment would correspond to assimilation. Generating and improving theories which guide our actions corresponds to accommodation. (Not all theories, however, can be consciously improved. Those which comprise inborn elements such as the meta- theory of physics, are excluded.)

Non-selective driving forces of evolution

In the same way as searching for true statements about the world is the driving force of most of today's science, the variation/selection mechanism, according to Darwinian adaptation, is seen as the driving force in organic evolution. This can be regarded in a somewhat more general context. Interactions between individuals (of whatever kind) can be divided into two classes: mutual benefit interactions (MB-Interactions) and unilateral benefit interactions (UB-Interactions). UB-interaction is equivalent to sheer competition leading eventually to selection of the winner. It is a zero-sum-game and it is the major element of Darwinian natural selection (further to selection by the physical environment). MB-interaction (which comprises all kind of communication), however, constitutes an added value and therefore will bring about new selection forces towards the conservation of the profitable interaction concerned. It may well happen that the added value from a special MB-interaction is greater than the profit from being selected as winner of competition. Then Darwinian competition will not pay. This makes it clear that one of the prevailing views in the units-of-evolution controversy that all living beings would fight their life battles on behalf of their selfish genes, holds only for those parts of evolution where gene- holders interact exclusively in terms of competition. As soon as any kind of communication comes up selection will act mainly according to the need not to lose the benefits concerned - sometimes even when a reduced reproduction rate has to be accepted: when eukaryotes "decided" to link together as somatic cells in higher organisms they assigned all their genetic rights to the germ cells and reproduced only according to the boundary conditions of their physiological environment. Those which forget this and reproduce maximally like "free and independent" cells will die as cancer cells. To a certain degree also men (as well as some socially organised animals) acquired the status of somatic cells. They still propagate (and, of course, they must do so) but mainly according to certain social criteria and not in order to maximise their "genetic output". Indeed, none of us would invest all his biological and social resources in bringing up as many children as possible. We are cultural individuals in so far as we strive for cultural rather than for genetic immortality (sensu Dawkins, 1982), i.e. we want our scientific, cultural or social merits to survive in human practice or public memory rather than to continue our specific genetic lineage. We strive for a lasting contribution to the "culture-pool" rather than to the gene-pool of our society. Some groups even resign explicitly (via celibacy) from any genetic propagation at all in order to be culturally or socially the more efficient. They recruit their members by social integration instead of biological replication.

The Darwinian theory concentrates on UB-interactions and natural selection as the prevailing driving forces of evolution - a defendable approach, provided that we consider only units high enough in the general hierarchy to interact exclusively through competition. This is the course pursued by the unit-of-selectionists: at what hierarchical level do we have to define living units which are subject to selection based on sheer competition?

The Darwinist (as represented by the synthetic theory) excludes that evolution can proceed by other than genetic changes. Phenotypic changes based on epigenetic modifications and the related phenomena of non-linear genetics are not considered. This means that any improvement of the Darwinian theory can take place only through more refined and subtle models of selection acting on allele frequencies as approached in population genetics. On the other hand, when extending the playground of evolution to epigenesis, the question will arise "why stop just here?" Once we have decided to give up the restriction of evolution to genetic mechanisms, the idea suggests itself the theory of evolution should also be extended to the topic of cultural devolution, particularly after we have seen that everything we called theories in a broader sense - from organic to social organisms and from organic tools and capabilities to scientific theories - evolves according to analogue principles. Having this wider notion of theory in mind, the most general theory of evolution, then, would be a "theory of evolution of theories" (TET) (Diettrich, 1989)

Evolutionary strategies

All the above mentioned communicative innovations that evolution has brought about (they may have been preceded by something similar and similarly important at the biochemical level such as that which Eigen modeled by his Hypercycle) have three main effects in common: 1. They constituted, as already mentioned, entirely new forms of biological, cultural and social beings. 2. They opened new opportunities being inconceivable at the previous level. Of course, eucaryotic evolution can never accomplish the functional capabilities of higher organisms which, in turn, can never hope to cope biologically with what scientific and technological evolution has brought about. 3. They caused evolutionary processes to come to a nearly complete halt at the preceding levels: As communication is possible only at the basis of a standardised "language", the more elementary elements upon which communication is based must be exempted from further evolution. Indeed, once genetic communication was generally established, the "language", i.e. the genetic code, was no longer modified. Once multicellular organisms were installed, evolution of the constituting cells subsided nearly completely (except a certain specialisation in the light of new requirements) and since mankind learned to master physical problems by technological means, the cognitive basis has to be guaranteed. Further cognitive evolution towards new categories of thinking and perceiving as a basis for a hopefully better science would be counterproductive, as it may bring about first of all a total incompatibility with all existing science. (Here again, with the exception of a certain specialisation in the light of new requirements such as the redefinition of space and time in the context of experimental results in higher physics). Evolution of whatever, and all progress based upon it, is a de facto monopoly of the highest existing developmental level.

These lines of thinking suggest that a general theory should see evolution not only under the aspect of genetic morphogenesis and heredity, i.e. of processes that generate the distinct morphologies of species and the mechanisms that stabilise these processes from generation to generation. It also should consider the aspect of changing interactions between units constituting by this new and higher units. A special interaction of this kind is sexual communication forming, as shown, the various species, i.e. classes of potential interbreeders. This was for a long time the prevailing interaction in biotic evolution. Then cultural and social mutual benefit interactions came up and posed restrictions upon genetic reproduction and therefore on genetic communication. So what competes or cooperates are the various forms of interaction rather than structures or biotic individuals. This applies a fortiori for cultural and social interactions which experienced a long and complex evolution from non-verbal to verbal communication, from written to tele-communication, from personal to anonymous interaction, from authoritarian to democratic adjustment of interest, and so on. Strictly speaking, individuals and other structural units cannot compete as such at all but by means of certain interactions. Structural characteristics are relevant for the course of evolution only in so far as they represent a certain functionality. So the relevant category in evolution is interaction rather than structure. Structures are nothing but the by-product or the realisation of certain interactions. Their evolution is an epiphenomenon as structures and functions are not correlated. Neither does a function determine by what structure it will be realised nor decide a structure for what it will be used. So, the analyses of structures makes sense only in the light of the interpretation by the strategies using them - in the same sense as genomic structures have no proper meaning except within the interpretation by the epigenetic system. This is the reason why a theory of evolution which deals primarily with the heredity and the change of morphologies will find it hard to provide deeper long-term explanations. For short-term developments, particularly in the context of a given strategy in a given environment, it might be possible to say which structural modification will be the better response. For any wider context, however, where external data as well as strategies could change, it may well suggest that a theory dealing with the notion of competition and selection should be approached in terms of interaction rather than of structures as competition and selection themselves are interactions. Here is an example of what that is to mean:

It is a speciality of biotic structures that they cannot change individually. Organic evolution can proceed only by means of non-identical replication of the phenotype. There is no somatic evolution. This has brought about another strategic element of evolution of higher organisms. Evolutionary differences between parental and daughter generations are usually so little that they will occupy the same eco-niches. So, the various generations will compete directly - with a clear handicap for the younger generation due to less acquired knowledge. This would be a serious barrier for organic progress if evolution had not invented the institution of natural death, cleaning continuously the limited market for life-goods from obsolete but still vigorous models. From the functional point of view, natural death is a direct consequence of the fact that the various genetic "ideas" or "responses" are materialised in different individuals rather than as different states of a single organism (such as the various homeostatic states which allow immediate responses to changing external data). With man, as we mentioned before, biological evolution became irrelevant or even counterproductive anyway. Progress comes with cultural, scientific and technical achievements (if only!) based on social cooperation. What competes or cooperates and then will evolve are the applied theories themselves rather than their carriers (according to the principle that evolution is primarily top level evolution). So, human birth and death are no longer an evolutionary must (except, may be, for some theories and ideas which despite their proven obsoleteness survive under the protection and for the lifetime of their prominent representatives, as shown by Thomas Kuhn). Human birth and death are strategic fossils of evolution from pre-social times.

One of the basic elements of Darwinian theory is that species would die out only according to missing adaptation to their physical or organic environment: there is no natural death of species. Thus the strategy of evolution is taken as (stochastic) production and subsequent selection of variety. The empirical evidence for this is beyond all doubt - but it may not necessarily be the only strategy evolution could apply. The idea of non-linear genetics suggests that there is an additional mechanism for both the rise and fall of species. Subsequent non-identical reproduction based on an epigenetic system which is not an eigen-vector of the genome may contribute considerably to phylogenesis. However, the faster evolution proceeds in this way, i.e. the greater the phenotypic differences are from one generation to the next according to non- identical reproduction, the higher will be the probability and the sooner it will occur that a lineage which does not happen to converge towards stable and identical reproduction will end with a non reproducible organism. So, times in earth history which are characterised by faster evolution will show a great typogenetic fertility, but the new species

concerned may also have a larger natural extinction rate which is not due to insufficient adaptation. This would explain why so many of the phyla brought about by the so called Cambrian explosion did not survive. However painful this is for the species concerned, for life as such it might be profitable as it would accelerate the procedure of trial and error and therefore of "learning" (Konrad Lorenz: "Life is an information gaining process"). On the other side, any evolutionary progress invested is lost if the species concerned dies out. So life cannot profit from quicker "learning" if it is combined with quicker "forgetting". Long-term learning is possible only with species which live long enough to accumulate more sophisticated evolutionary achievements, i.e. which "withstood" the temptation of too fast evolution. Below we will see that what we call an achievement is not aprori a progress as it can be both chance and risk. So we cannot say that the older species are, the better they survive. What happened since Cambrian times is just a change of strategy, away from rather quick realisations of new evolutionary ideas in many short living lineages towards the development of several ideas within single lineages. Evolution has applied this strategy several times, and each time in a more sophisticated manner. Homeostasis belongs to this. Instead of replacing organism well adapted to cold temperatures by those which like warmer climate in case this is required, evolution brought about organisms which can cope with both conditions. This generalisation has been perfected with men who, by means of scientific achievements, can cope with nearly any physical requirement and therefore no longer depend on organic evolution at all.
This opens up the general question as to the success and its predictability of organic and cultural structures and strategies, i.e. of theories in the broader sense with a particular view to what we call fitness and survival.
Fitness is defined as the quality which contributes to the survival of a species - in the narrow sense if only genetically determined qualities are concerned, and in the broad sense if also culturally inheritable forms of behaviour and capabilities are considered, up to scientific and organisatorial skills of homo sapiens. Though not a custom, we will attribute fitness also to theories or strategies if they succeed for a long time and under a variety of conditions. A sufficient condition for biological survival is a high reproduction rate, but it is not necessary: we have seen in the previous section that under the conditions of a profitable social cooperation maximal procreation might be counterproductive and that a restricted and modest reproduction rate could be the better guarantee for long-term survival.
Yet, fitness is a theoretically fruitful notion only if it is more than just a synonym for the ability to survive, i.e. further to its result it must manifest itself also in other qualities from which, then, one could draw conclusions on the species' future position. Otherwise one would run into the well-known tautology of the "survival of the fittest". It would be sufficient, for example, if we could deduce from a species which survived up to now that it must have developed so many survival skills that it will have good chances of succeeding also in the future. But this is exactly what we cannot do. Special species have developed special skills tailored for the special difficulties of the past, but not necessarily of the future - and particularly not for those they have brought about themselves by what they tried in the past. The more sophisticated and comprehensive are the problem solving techniques a species has engineered, the more sophisticated and comprehensive are the problems which will result just from this, and the more expensive and troublesome are the efforts needed for mastering the new problems. Nearly all problems mankind has nowadays result from nothing but the success our ancestors had in solving their problems. Under these circumstances it is not at all evident that man, despite all his problem solving capabilities, has less reason to worry about his future than many of the eukaryotes. What is more: as with increasing efforts and investments the risk grows of colliding with the boundary conditions of our existence, i.e. to become the victim of irreversible life threatening long term consequences, it cannot be

excluded that progress understood as intended for the conservation of species, may well turn out to be counterproductive. What looked ingenious in its time could have been the first step into a dead end street.
This can be described also in a somewhat different way. There seems to be something which could be called risk-homoeostasis (G.J.S. Wilde, 1982). All successful evolutionary solutions of problems diminish the extinction risk of endangered species. On the other hand species are tempted to load new risks on the strategic reserves just acquired. The net security yield, therefore, may be zero, or even negative in case of overcompensation. Animals, for example, which can not only walk but also fly should, under otherwise equal conditions, be better adapted then those which can only walk or only fly - but only as long as their greater competence will not entice them to occupy biotopes where both walking and flying is a prerequisite for survival, so that already the loss of one of these abilities would be fatal. Not much better off is the cardriver who wastes the security benefit from the additional technical facilities of his car, such as ABS brakes, by driving at a correspondingly higher speed - a behaviour which unfortunately is very common as insurance companies confirm.
This is a very general principle: the number of potentially fatal problems man has brought about by nothing but completely exploiting their various capabilities, is not much smaller than the number of the capabilities themselves, as any problem solving implicitly comprises the generation of new problems which in most cases are more complex as they derive from a solution which must have been superior to the previous problem. In terms of ecology: the greatest problem of mankind is probably the waste management of man's capabilities.
We firmly believe that there are general strategies which are useful and therefore recommendable in any situation, though their long term profit may be reduced by the mechanisms of risk-homoeostasis - functionally "true" strategies so to say, similar to structurally true propositions on the real world. To improve and strengthen the methods of rational thinking is seen to be of this general utility not only in science but also in the world of day-to-day living. From what we understand as the success of rationality it is often derived that it must be based on the constitution of the world we live in, and, consequently, that the world's order can be decoded only by means of rational methods. From this, then, we conclude that even in those cases where a consciously applied rationality can be excluded (as in the subconscious or with animals' behaviour) the success of strategies or the applicability of organs is guaranteed only and insofar as they meet rational criteria, i.e. insofar as they are 'ratiomorph' (E. Brunswik, 1956). This means that strategies and construction principles (concerning both the physical and the cognitive context) have to consider all relevant facts in the same way as an accordingly informed analyst would do.

The shift to the social paradigm in human evolution

To derive the "rational structure" of our world from the success of rationality and to conclude retrogressively that cognitive methods can survive only when being ratiomorph reflects the allegation that rationality results from cognitive adaptation to the real world (Campbell speaks in terms of "natural-selection-epistemology"). As, however, the notion of an independent reality evaluating the efforts of those dealing with it, cannot be explicated as we have seen, the success of rationality can hardly characterise the world as it is but only the class of rationally solvable problems. So, the ability of rational thinking cannot represent a value per se based on the particular constitution of the world. Its utility can be defined only in the context of the various applications concerned. Indeed, the high reputation rationality has enjoyed since the days of the enlightment, particularly in the context of science and technology, is mainly based on man's decision to favour just those values (such as the physical mastering of nature) which can be satisfied only by means of rational methods. The development of these methods, in turn, stimulated technology based cultural achievements such as telecommunication, which, in turn generated incentives for further research in this direction. This holds rather generally: there is an inherent co-evolution between all means and their application in general behaviour, cognition and culture as well as in organic life. It refers to rationality and control of nature (or more particularly: basic research and technological applications), biological limbs and manual intelligence, visual sense organs and space-time perception, physical theories and experiments (as described above) or feeding tools and feeding habits, and so on. None of these tools would make any sense or could be evaluated except in the context of the applications with which they had evolved together. Particularly it cannot be said that species with rational capabilities would dominate necessarily all other species. With a view to the large number of unsolved human problems based primarily on a lack of social coherence rather than of scientific knowledge, it cannot be excluded that societies specialised in intuitive (and therefore irrational) social problem management would, in the long run, be better off than societies with a high scientific standing but without the necessary feeling for what the social consequences of science could be.

This can be derived also from another line of thinking. For a long time in human history, the world man had to cope with was the physical environment and physical were the problems man had to master in order to survive. The fight against cold, hunger and disease dominated human striving for ages culminating eventually in modern science and technology solving nearly all of our classical problems. As to the scientific possibilities available, mankind is largely saturated. With increasing social communication, however, the relevant environment is shifting more and more from the physical to the social environment opening by this an entirely new set of requirements. Looking at the course of one of our days, it is obvious that we spend most of our efforts to meet social boundary conditions, such as to make money or to find acceptable balances with other peoples' interests, rather than to grapple directly with physical needs. Even if we deal as scientists explicitly with the physical structure of our environment, we mainly do so in order to survive in the academic rather than in the physical world. In the long term this may reduce the general curiosity about scientific-technological issues and the perception of the physical environment in favour of a sharper comprehension for societally relevant matters. Under these aspects, the high strategic importance we attribute to scientific and technological capabilities is a relic from times where the mastery of nature was the prevailing requisite for survival. Nowadays, most of the problems we have and even more of those we will have in future are social in character or can be solved only by social measures. So it may well be possible that the (Occidental) cultural dominance of the science of nature which followed the religious paradigm is a fading episode in man's history replaced by what one could call the societal paradigm.

I would hesitate to see in the present widespread anti science movement, as manifested particularly in the field of nuclear energy or biotechnology, a first indication for a paradigmatic shift in the sense discussed here. On the one hand, these attitudes refer to fears and concerns about fatal applications or otherwise risky consequences related to mismanagement, lack of control or neglecting the non-renewable character of many resources, rather than to a general re- evaluation of the goals to be achieved by science. On the other hand, however, the fact that science is raised at all as an issue on the public agenda makes it clear that science is going to shift from being a pure survival tool such as agriculture was, towards one of the societal "enzymes" which constitute the mechanisms of social development as described by N. Luhmann (1990).

For the time being one of the most severe difficulties mankind has ever been confronted with is environmental pollution which is no doubt physical in character. Even this, notwithstanding, is first of all a social problem as it requires socially reasonable responses diminishing the causal output rather than scientific efforts. Scientific solutions, however ingenious and effective they may be, cannot eliminate the mechanisms of risk homoeostasis, i.e. they cannot prevent a counter-productive increase in the detrimental production so that, after a while and despite all technical environment protection skills we have, the old pollution values will be reached again - if not even more. Unfortunately there are many similar problems where the often fascinating scientific success in fighting them prevents us from looking at the very, i.e. the societal, solution.

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