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When science fails us

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Richard Levins *looks at the dramatic failures of Euro-North American science, and argues for a science that looks more broadly at our relationship with the rest of nature. This is an edited version of his address on receiving the 1996 Edinburgh Medal.*

Modern Euro-North American science has developed technologies which seemed to promise a deeper understanding of the world and a better life for humanity. And indeed its achievements are impressive: we can read the composition of distant galaxies from tired bits of ancient light, we can decipher the histories of the rocks formed a billion years ago and the diets of species long gone. We can track the movements of molecules and of caribou, sequences of genes and civilizations. We have bred plants and animals to fit our technologies, invented new ways of communicating and of diagnosing diseases and predicting the weather.

But science also has had dramatic failures. The promises of understanding and progress have not been kept, and the application of science to human affairs has often done great harm. Public health has been caught by surprise by the resurgence of old diseases and the appearance of new ones; modern planning has not given us more liveable cities; industrial design for greater efficiency has not made work more humane but has instead led to increased bodily stress, anxiety, overwork and unemployment; pesticides increase pests, create new pest problems and contribute to the load of poison in our habitat; antibiotics create new pathogens resistant to our drugs; modern high-tech agronomy watches our soils disappearing; the green revolution did not eliminate hunger but increased the polarisation of rich and poor, and the dependence of developing countries on imports; scientific theories have been put forth to justify inequality, racism, aggression and competitiveness.

I am sure that all of you could add to the list of major problems that science has not only not solved but has even made worse through the invention of technologies that intervene strongly into complex processes with simple-minded expectations. It is no wonder that we see an anti-science backlash, with cuts in expenditures for research and the education of scientists, the turning of young people away from the scientific vocations, a counterposing of scientific knowledge to humane or spiritual feelings and morality, and attacks on scientific rationality itself.

It is natural that scientists and other intellectuals rush to the defence of science, but some of the criticisms are valid. There are, broadly, two very different kinds of criticism, one conservative and one radical, from very different sources and pursuing very different goals. Conservative criticism rejects the very goal of science, to understand the world in order to guide our actions. Its advocates often brush aside scientific evidence in favour of theological claims. They misuse the mathematics of 'chaos' to deny the essential intelligibility of the world. They recognise the social conditioning and the ultimate fallibility of science, but use this as an excuse for refusing to distinguish the relatively true from the dreadfully wrong. These critics usually praise technology while damning the intellectual independence of science which made that technology possible. Their ideal would be technically well trained, docile and specialised researchers inventing ever newer and more sophisticated means while remaining unreflective about ends.

Radical criticism, however, shares the old scientific goals of understanding the world for making life better. It taxes science for its failure to live up to its own stated principles. It argues that military secrecy and corporate proprietary rights directly deny access to knowledge and that the high cost of research denies it in practice. This means that we can no longer undertake the independent verification that was the cornerstone of the democracy of science, and the guarantor of its objectivity. The costs of an education, and economic inequalities, make access to the scientific community a matter of privilege. Furthermore, hierarchies of credibility and rich vocabularies for putting down uncomfortable ideas - 'far out', 'faddish', 'cranky', 'not mainstream', 'ideological' or 'unproven' - negate the spirit of open-minded inquiry, while the need for continued funding and prestige makes it important to be first and to be right rather than to be self-critical and open. Thus a cult of expertise and credentials thwarts the democratic, egalitarian spirit of science, so that arguments are not given equal opportunity regardless of their source.

This criticism also challenges some of the core principles of science themselves. For example, the demand to examine ideas without reference to their source, an expression of elementary fairness, also prevents us from understanding the context of innovation, the reasons for science following one agenda and not another. The call to separate thinking from feeling or facts from wishes, so crucial in the struggle for objectivity, encourages the passive impersonal mode of scientific writing that hides the history of and reasons for an investigation. It has allowed scientists to participate in the most heinous crimes with a sense of righteousness.

A good radical criticism aims at a democratic, humane and creative science that looks at our relation with the rest of nature in its broadest context, that would combine specialised research with self-reflection and with frequent re-examination of goals. It seeks a renovation of science that revives some of the old traditional goals but also proposes new ones.

In what follows I will discuss three areas where scientific disciplines have had great success in the small but failed us in the large; I will then consider some of the common features in their failure, and, finally, suggest a programme for the revitalisation of science.

The epidemiological transition

Two or three decades ago the expectation was that infectious disease would decline and be replaced by chronic disease as the major health problem in the world. This expectation was labelled the epidemiological transition and remained the prevailing dogma in public health even after the resurgence of malaria, tuberculosis, cholera and dengue, and the appearance of AIDS, Lyme disease, Ebola virus, Marburg virus, Lassa fever, toxic shock syndrome and Legionnaire's disease. As each new disease appeared it was studied urgently and knowledge of the infective agent, its means of transmission and approaches to treatment appeared quickly. Genes were sequenced, tests invented and surveillance systems designed to detect new cases rapidly. But new diseases continue to appear and old ones reinvade.

That science was caught by surprise by the resurgence of infectious disease is in itself not surprising. Surprise in science is inevitable because we have to study the new by treating it just like the old. This makes science necessary and simple experience insufficient. But it also makes surprise inevitable and guarantees that we eventually meet situations where our old ideas no longer hold and perhaps never did.

However we do have the obligation to understand why enormous errors were made, and to recognise and correct them as soon as possible. In order to do this, we first have to understand why the idea that infection would decline seemed so plausible in the 1970s. My working hypothesis is that our scientific predecessors were just as smart as we are, and if they reached the wrong conclusions, they did so for good reasons. There were three supporting arguments. Firstly, it could be seen that infectious disease had been declining for over a century. Smallpox was on the verge of complete eradication, tuberculosis was in retreat, a polio vaccine removed the annual panic of infantile paralysis. Secondly, new drugs, antibiotics, better vaccines, more subtle diagnostic techniques were being invented to increase our tool kit, while our adversaries, the bacteria and viruses and fungi, had to rely on the same old tools of mutation and recombination - surely this would tip the balance in our favour. Thirdly, it was proclaimed that international economic development programmes would end poverty, and the new affluence would allow all countries the resources to apply the most modern techniques of disease control. It would also give us longer lives and an older population. Since most infectious diseases attack children, we would be less vulnerable to them.

These were plausible arguments, but they were wrong. And the ways in which they were wrong prove very enlightening.

A century or two is too short a time period to justify the claim of a definitive end to infectious disease. If we look instead at the longer sweep of human history we see diseases rise and fall. The first pandemic of plague that we can confirm in Europe emerged and subsided during the collapse of the Roman empire, the second as feudalism entered its crisis in the fourteenth century. The conquest of the Americas was perhaps the most devastating epidemiological event of recorded history. Plague, smallpox, tuberculosis and other diseases combined with the hunger caused by the breakup of indigenous productive systems, and direct massacres, to reduce the population by as much as 90 per cent in the two centuries following Columbus. This public health disaster lasted two centuries and in some ways is not completely over.

Thus the doctrine of the epidemiological transition is better replaced by the proposition that whenever there are large-scale changes in society, climate, land use or population movements there will also be new epidemiological problems.

It was not the lack of knowledge of history that caused this lack of attention to the long sweep of history. There was a sense that our own time represented so radical a break with the past that what happened back then was irrelevant, or, in the words of Henry Ford, 'history is bunk!'

There were other aspects to the narrowness of thinking about disease. Medical science is concerned only with one species, the human. But if public health workers had looked also at veterinary and plant disease, it would have been more obvious that disease is a general phenomenon of evolutionary ecology. All groups of animals and plants have parasites. There are even bacteria that parasitize protozoa, others that infect roundworms, and bacteria and viruses that parasitize bacteria. Parasitism involves complex patterns of adaptation and counter-adaptation, with no evidence for a long-term trend to their elimination. Looking at a wider range of species, health workers would have seen diseases spreading and contracting, spilling over into new hosts and presenting different symptoms and microbes competing with or enhancing each other's capacity for mischief. They would have been sensitive to the epidemiological consequences of deforestation, irrigation, new patterns of human settlement. The experience of agriculture, that pests become resistant to pesticides, would have reinforced the observations of drug and antibiotic resistance to warn that whenever we change the conditions of survival for an organism, the evolutionary pressures on it will be changed and it will respond one way or another.

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Disease is not merely a question of a pathogen finding a host; nor is medicine a question of a drug killing the pathogen. Whether a germ successfully establishes itself in a person, and whether it is able to invade a population, depends on the vulnerabilities of both. This is influenced by the status of the individual's immune system, which may be depressed by other diseases, malnutrition, stress, drugs and pollutants, and by other less well studied aspects of disease resistance.

Another aspect of the narrowness of thinking about disease is the separation of the biological from the social. A social epidemiology would begin with the proposition that human biology is a socialised biology. This is true of our physiology: eating is not understandable merely as the biochemistry of nutrition. What we eat or refuse to eat, who eats and who does not eat, how much we eat, who determines what is eaten, who you eat with or wouldn't be caught dead eating with, who prepares the food and who washes up, are all consequences not only of the physiological fact that we have to eat, but also of the social arrangements around eating. Breathing is not a passive result of respiratory metabolism. How we breathe is related to stress, air quality, perceptions about the social environment and our emotions. Posture and biomechanical stress, the back aches and stiff necks and painful joints and muscles, are not the passive consequence of our species walking erect but of who we are in society, what kind of work we do and what feelings we are expressing or suppressing, and what we are trying to convey with our postures. Pantomime actors grasp this exquisitely, and in an instant convey to their audiences whether they own an estate or are slaves on that estate, whether they are important, dangerous, accommodating or insignificant. More obviously, sex cannot be understood simply as reproduction.

Human genetics and ecology are also social. If epidemiologists had been more sensitive to how society penetrates our bodies, genes would not have been so readily accepted as independent and sufficient explanations of patterns of prevalence of diseases. All genes do is make proteins or influence when the proteins are made. What happens next depends on the environments within the cell, in the body as a whole, and in the community where that body develops and on the complex interactions among genes, the organism as a whole and the environment. Genes may influence which environments an organism is exposed to. These environments then affect the rate of mutation of the genes. They determine which genetic differences show up as organism differences, and which genes are selected.

We have transformed our environments. The composition of our outdoor and indoor atmosphere has been supplemented by tens of thousands of new chemical compounds which interact in unsuspected ways. Productive activity takes place at temperatures, at paces, and at hours of the day and night that are historically new for our thermoregulatory mechanisms, our serotonin rhythms and our muscles. Giant cities and the special habitats of prisons, nursing homes, schools and refugee camps offer previously unexperienced population densities. Sealed buildings and barely recycled air in aeroplanes create new habitats for pathogens and increase exposures to airborne viruses. New patterns of alienation, social harassment and anxiety demand that our physiological and psychological responses that evolved for emergencies cope with chronic conditions. If we could step back from the details and squint we would see patterns: our societies make us sicker in a thousand ways and then invest ever more resources trying to repair the damage.

A social epidemiology could be sensitive to the complexity of the pathways linking general aspects of society through our nervous systems and neurotransmitters to the various kinds of white blood cells that fight infection and sometimes turn against us. The outcomes of infection depend on these same factors and also on the availability and effectiveness of medical care. And they obviously are not distributed evenly across countries or within countries. They are certainly not distributed evenly across diseases, where the pattern of knowledge and ignorance is influenced by whose diseases they are.

The expectation that the new technologies of drugs, antibiotics, pesticides and vaccines would 'win the war' with the pathogens grossly underestimated the dynamic capacity of organisms to adapt and the intricacies of natural selection. Microbes not only undergo mutation but also can receive genes from other species. Therefore genetic variation is available for selection. Therapies that threaten the survival of the germs also focus natural selection on overcoming or evading those therapies. The genetic make-up of pathogen populations therefore shifts readily, not only in the long run but even in the course of a single outbreak and within a single host during a bout of illness. Strong opposing demands on the pathogen's biology select for access to nutrients, avoidance of the body's defences and exit to a new host. Variations in the state of nutrition, the immune system, the presence or absence of other infections, access to treatment, the treatment regime and conditions of transmission push and pull the genetic make-up of pathogen populations in different directions so that we constantly see new strains arising that differ in their drug and antibiotic resistance, clinical course, virulence, and biochemical detail. Some even develop resistance to treatments that have not yet been used if these threaten the survival of the pathogens in ways similar to old treatments. As long as we see nature as passively absorbing the impacts of our interventions we will be caught by surprise by the failures of previously successful interventions.

The third reason that public health professionals expected the decline of infectious disease was the belief that the economic penetration of capitalism to the furthest reaches of the globe would eliminate hunger and provide health care for all people in all classes in all countries. This assertion was accepted implicitly without examination. It was part of the cold war mythology, and therefore challenges to it could be dismissed as enemy propaganda. Only now can mainstream social science acknowledge the growing gap between rich and poor countries, and within countries, and ask why the earlier expectations have not been realised. And only now can public health confront the growing inequalities as a serious public health issue.

Thus public health was caught by surprise because of several kinds of narrowness: a short time frame, limitation to only our own species, isolation from evolutionary ecology, and a failure to come to grips with the pressing social issues that affect vulnerability. In order to be up to the task it faces, an integrated epidemiology would have long time horizons, broad species ranges, be rooted in evolutionary ecology and social theory, respect and study explicitly the structure and dynamics of complex systems, and look critically at its own history. These are characteristics of what would be a dialectical epidemiology.

Of green revolutions

The problems and failures that beset public health have much in common with those in agriculture because agriculture is like medicine in many ways. The objects of interest in both fields are simultaneously biological and social. Both agriculture and health researchers are trying to solve urgent problems of human welfare and therefore are often impatient of theory. Both have received generous public support as well as private corporate investment. The products *of* that massive research effort mostly have been turned into commodities and marketed for private gain.

In both medicine and agriculture practice often does more harm than good, often enough that we have special terms to describe these failures: iatrogenesis, the causing of disease by doctors; nosocomial infections that arise in hospitals; secondary pests that become threats to food production only after intensive pesticide use. In both fields, we have achieved great sophistication in the small, but this has been accompanied by a growing irrationality in the large. Finally, dissatisfaction with both fields has led to the growth of 'alternative' movements such as herbal medicine, homeopathy, naturopathy, organic and biodynamic farming.

Over the last few centuries average agricultural yields increased as a result of the application of mechanisation, chemicalisation (fertilisers and pesticides), plant and animal breeding, and scientific management. Although problems arose, it was widely believed that these were the costs of progress and would be solved by the same means that created them. But starting in the 1960s there has been increasing criticism of the high-tech pathway of agricultural development. The different criticisms have come from different sources with different concerns, but also flow together into a coherent theoretical and political critique:

1. Modern high-tech agriculture has not eliminated hunger.
2. It undermines its own productive base through erosion, soil compaction and salinisation, depletion of water resources and of genotypic diversity.
3. It changes land use patterns, encouraging deforestation, draining of wetlands, planting crops according to market criteria even in unsuitable climates. It promotes a loss of crop diversity by specialisation and commercial seed production and reduces overall biodiversity through its chemical inputs and extensive monocultures.
4. It increases vulnerability to nature, especially to climate and microclimate change, pest outbreaks and atmospheric and water pollutants because of large scale monoculture, the selection of varieties for maximum yield under optimal conditions and the loss of beneficial fauna and flora.
5. It makes farming increasingly dependent on off-the-farm inputs, and therefore on cash flow, as fertilisers replace natural nitrogen fixers, irrigation replaces the broken hydrological flows and storages of water, pesticides replace natural enemies of pests and hybrid seeds must be bought. Dependence on external inputs increases the vulnerability to price instability and politically motivated trade policies.
6. It debases food quality as regional specialisation increases storage and transport time, crops and techniques are chosen for quantitative yield, and specialisation makes even farmers dependent on food purchases.
7. It increases the gap between rich and poor. The rich are able to buy or get credit to buy the new inputs, establish the marketing connections and average their returns across years while the poor need to be successful every year. It especially undermines the economic independence of women. The new technologies are usually given to men even where women traditionally did most of the farming. The new technologies make the domestic chores of women, such as gathering firewood and fetching water, more time consuming; and women's diverse activities in the home conflict with the extreme seasonality of commercial monoculture.

8. It poisons people, first the farm workers who handle pesticides, then their family members who handle the pesticide soaked clothing and drink water where pesticides and fertilisers have run into ground water. Finally it reaches those who eat the crops produced with pesticides and animals raised with antibiotics and growth hormones.
9. It poisons other species and the environment as a whole, with eutrophication of our waterways from fertiliser runoff, accumulation of pesticides in the body tissues offish and birds, and nitrification of the air.

Despite its technical complexity, modern agricultural technology has a narrow intellectual base susceptible to surprise. The final conclusion is that the commercialised, export-oriented high-tech agriculture is a non-sustainable successional stage in the ecology of production, like the shrubs that squeeze out the grasses and herbs of an abandoned field only to create the conditions for their own replacement by trees.

What I have described as a successional stage is seen by proponents of modernisation as a desirable end goal. Modernisation theory assumes that there is only a single pathway of development, along the single axis from less developed to more developed, and that the task of the less developed is to become like the more developed as quickly as possible. Modernisation theory proposes that:

1. Progress moves from labour-intensive to capital-intensive production.
2. Progress moves from heterogeneous land use to homogeneous land use devoted to the most advantageous crop.
3. Progress moves from small scale to large scale to take advantage of the economies of scale.
4. Progress moves from dependence on nature to control over or replacement of nature.
5. Progress requires the replacement of traditional knowledge, labelled 'superstition', by scientific knowledge.
6. In science, modernisation theory asserts that progress moves from broad general knowledge to increasingly narrow specialisation, and
7. Progress moves from the study of natural objects to their smallest parts.

But an integrated, agricultural science equally rooted in natural science and a critique of society would recognise that we have to move beyond the capital-intensive model where great masses of energy are applied to move great quantities of matter, to a low input, gentle, thought-intensive technology that nudges more than it commands and reduces dependence on purchased equipment and chemicals. Such a system is less energy-costly, preserves productive capacity, and protects the human population and our habitats.

An integrated agricultural science would reject both the random heterogeneity of land use imposed by land tenure, and the homogeneity of the plantation. It would propose a planned heterogeneity in a mosaic of land uses where each plot of land contributes harvestable products and also facilitates the production on the other plots. Forests would provide wood and fruit and honey but also modulate the flow of water, alter the microclimate out from the edge, house birds and bats that consume pests, and offer restful shelter to people. Pastures could provide livestock, manure for biogas and to fertilise vegetable beds, nectar sources for parasitic wasps that control pests, fix nitrogen and control erosion. Elements of such a system are already in practice in many places. In Cuba, alternating strips of bananas and sweet potatoes or intercrops of corn with sweet potatoes provide the shade and nesting sites that allow predatory ants to control pests of sweet potato. Occasional rows of corn among the peppers divert the fruitworms from the peppers. Organic farmers in the United States use marigolds to repel nematodes and beans to protect tomatoes from the late blight as well as to fix nitrogen. Maize roots reach deep down and bring up minerals from lower layers while shallow rooted crops hold the soil. Ponds produce fish and predatory dragonflies, ameliorate the microclimate, are a reservoir of water for fire fighting and a place to swim.

The unit of planning need not coincide with the unit of production. The sizes of plots need to reflect the scales over which beneficial interactions occur. The mosaic of different land uses can combine considerations of crop rotation, buffers against natural and economic uncertainty, a diverse diet, differential labour requirements, and compensating diversity of more and less profitable crops.

Modernisation's attempt to remove our subjection to the uncertainties of nature by a complete control over all the processes on a farm cannot be successful. But we can confront uncertainty through a mixed strategy, of detection of problems in time to do something about them, prediction of likely events, design of a buffered system tolerant to a broad range *of* conditions, and by prevention. All of this requires intellectual detours from the narrowly practical to understand the long and short term processes in their rich complexity. This is part of what I mean by a dialectical perspective.

An integrated agro- ecology would respect both traditional and scientific knowledge. The one is derived from a detailed, intimate, perceptive and very specific familiarity that people have with their own circumstances; while the other requires some distance from the particular in order to compare and generalise. Each has its areas of insight and its blindnesses, so that the best conditions for producing knowledge are those that allow farmers and scientists to meet as equals.

Agriculture has to be guided by a broader scientific vision. We must reject the reductionism that gives priority to molecules over cells and cells over organisms and organisms over populations. I insist that in addition to modern molecular biology there is also a modern physiology, modern anatomy, modern ecology, modern biogeography, modern sociology.

Protecting the environment

Environmental awareness is not new. Movements for the preservation of nature, usually of the relatively unexploited parts of nature, have existed for over a century. Concern for the inhabited environment also has a long history. In the US the Environment Protection Agency was established in 1970, and there are now many international agencies concerned with one or another aspect of environmental protection. The Soviet Union had some of the earliest and most stringent and thoughtful (and unenforced) laws for environmental protection since the 1920s. Costa Rica has adopted a bold programme to set aside vast areas as national parks. Nevertheless, industry continues to pour $C0_2$ into the atmosphere, the forests still blacken under acid rain or yield to the chainsaw, fish populations decline and carcinogens accumulate, and Costa Rica is leading the world in the rate of loss of rain forest to banana plantations and impoverished peasants.

There also have been dramatic reversals of the destructive trends. There are salmon in the Thames again, and reforestation in Japan. The Hudson River is cleaner and smog has declined in London. It seems as if no local environmental problem - except for some of the radioactive contamination sites - is completely unremediable. However, each time a forest or pond is saved it becomes harder to save the next one. Arguments are offered about 'going too far', or play off the environment against 'the economy'. Corporations that have never cared a fig about their workers suddenly become champions of job protection in order to have a free hand to cut down forests.

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The history of environmental degradation is a history of greed, poverty and ignorance. By greed I do not mean the individual idiosyncratic greed that might yearn for three yachts where two would do. Rather I refer to the institutionalised greed of business that has to expand to survive, that is always looking for new products, ways to create new needs, ways to cut costs by reducing environmental safeguards or evading the enforcement of existing ones. At a time when there is growing awareness of the need for an 'ecological society', the incompatibility of that goal with an economy driven by greed has not yet been assimilated. Proposals are still being offered to reconcile two very different modes of relating to nature.

While ecological necessity seeks sustainability, the commodified economy needs growth. This growth can be achieved by producing more of the same things, by making familiar commodities bigger, more complicated or with more elaborate packaging. Growth can be achieved by inventing new ways of turning natural conditions into resources for exploitation, by finding technical means for making more and more of our lives marketable, and by investing great effort into creating new needs for consumption.

While ecology stresses interaction, environmental protection law depends on assessing separable liabilities. The courts cannot disentangle the complexities of nature, so that sometimes awareness of interaction protects the polluters more than the environment.

While ecology values the uniqueness of materials, places and living things, the economy sees them all as interchangeable commodities measured on the single scale of economic values. Therefore there is no special virtue in preserving a resource. It may be economically rational to use up a resource totally and then move to the next investment.

While ecology values diversity, economic rationality favours going for the single most profitable crop, and great quantities of a single commodity, to benefit from economies of scale.

There exist movements resisting untrammelled greed. The destruction of particular habitats has been halted, some noxious substances have been removed from the atmosphere, important victories have been won. But growth itself cannot be retarded, the valuing of nature on the single scale of money cannot be eliminated, and new hazards can be invented faster than they can be studied and outlawed. Thus the complexities and anomalies of protecting our environment arise from a deep conflict between the ecology and the economy.

The ignorance which contributes to environmental degradation is not the passive absence of information but a constructed mix of data, gaps in data, data about irrelevant things, unrealistic expectations, fragmented knowledge, rigid categories and false dichotomies. It hides the impacts of economic activities and technical choices and narrows the scope of inquiry. It also obscures the processes of choosing among alternatives by the use of euphemisms such as 'the economy' to stand for profit, 'decision makers' for the owners or their representatives. It hides within the language of cost/benefit analysis the separation between those who pay the costs and those who get the benefits and pretends that a neutral optimisation process reconciles the interests of all parties when more usually all it can do is ratify existing relations of power.

The general critique

The problems of health, agriculture and environment are complex problems. But so is engineering. Before the space ship Challenger exploded it was quite common to hear the exasperated query, 'But how come we can put a man on the moon and yet not...' The 'yet not' could be to eliminate hunger or cure AIDS or save the rainforest or any other of a growing list of stubborn problems. The question was usually rhetorical, not a search for an answer but a cry of protest against misplaced priorities. But it is a serious question and deserves careful attention. I think there are three major reasons for the intractability of these problems.

First, there is the acceptance of hidden and unacknowledged side conditions. We want to provide health care for all, but subject to the side condition that the pharmaceutical industry continues private and profitable, and in backward countries such as mine that health insurance and even medical service itself are provided for gain. We want to preserve rural life, subject to not infringing on the power of the landed oligarchies. We want to respect the cultures and land rights of indigenous peoples, subject to the side conditions that the oil monopolies can use the subsoil unimpeded. We want to encourage food production, subject to the side conditions that imported food products can enter the third world markets freely and compete with peasant cultivators. We want a poison-free atmosphere, provided we do not intrude on the trade secrets of the polluters.

The second set of reasons is institutional. Ministries of health do not usually speak to ministries of agriculture and doctors do not talk to veterinarians or plant pathologists. This is especially a problem in the United States where plant pathology and veterinary medicine are taught in the universities of the land grant system run by state governments while medical schools are mostly in private urban universities. Corporations guard their product information from each other and the public. The systems of rewards and promotions for scientists place a premium on short term reductionist research that is most readily turned into marketable commodities. The tables of organisation of a research centre or university reflect and reinforce barriers among disciplines. Further, the studies of different objects are often arrayed on a hierarchical scale with ranking by the size of the object (the smaller ones being more 'fundamental') or along a 'hardness-softness' axis. In biology, the students of the small have appropriated the term 'modern' for their own fields.

Finally we come to the intellectual barriers to solving these problems. The problems are complex in ways different from those in engineering where the parts are produced outside of the wholes and perform in the laboratory more or less the way they will perform in the assembled systems. In eco-social systems it is not always clear what the appropriate 'parts' are, since they evolve and develop together and have only temporary existence away from their 'wholes'. The objects that have to be analysed together, such as the microbes themselves, the nutritional levels of populations and the behaviour of health bureaucrats, have been assigned to different disciplines.

The barriers all derive from the very powerful reductionist strategy that created Euro-North American science in the first place and made possible its dramatic successes but also its special blindnesses. The choice of the smallest possible object as the 'problem', the division of a problem into its smallest parts for analysis, the holding constant of everything but one factor at a time, the examination of static descriptions before the looking at the dynamics, the subdivision of the research process itself into the separate stages of assembling the 'facts' and the making of theories, all had their historical justifications in the struggle for scientific objectivity against several adversaries, including theological authoritarianism and also the introspections of natural philosophy and other unanchored speculations. The reductionist tactics have temporary value as moments in the scientific process. There is nothing wrong with identifying cell types or sequencing DNA or measuring energy. They are research tactics, and may be useful or not according to the specific situation. But as a philosophy of nature and society, and as the dominant mode of investigation, they are responsible for many of the dramatic failures of scientific programmes.

'things are the way they are because they got this way, not because they always were or have to be or will always be this way'

It is necessary in all research to make distinctions, to identify objects of interest as separate from other objects, to recognise different kinds of processes and causes. But science often stops there, without then putting back together what it has separated physically or conceptually. It imagines that our own creations, what we do for purposes of study, are valid descriptions of reality. False dichotomies such as heredity/environment, physical/psychological, equilibrium/change, science/ideology, thinking/feeling, biological/social, random/determined, order/chaos, lawfulness/historical contingency, life style/social conditions, have wrought havoc with scientific analysis, forcing choices between alternatives that really are not mutually exclusive. Instead of confronting the richness of interaction and interpenetration, scientific analysis often resorts to statistical devices to assign relative weights to different factors. Once we have done this, we can imagine that we have described complexity when what we have really done is reduce that complexity to a sum of 'factors'. Criticism of these and other false dichotomies is both a necessary step in the revitalisation of science to make it capable of confronting the enormous problems our species is now facing, and a major aspect of a dialectical approach.

But when we abandon the reductionist programme we are confronted with phenomena of daunting complexity, and without the tools for examining that complexity. The study of complexity requires a focus on change. We have to ask two fundamental questions about the world: why are things the way they are instead of a little bit different, and why are things the way they are instead of very different. The first is the question of self-regulation, of homeostasis, of the network of positive and negative feedbacks that absorb, transform, relocate and negate perturbations so that systems remain recognisably what they are despite the constant buffeting of opposing forces. It is the domain of systems theory proper, which takes a system as given and asks how it behaves. The second is the question of evolution, history, development, non-equilibrium theory. It starts from the simple proposition that things are the way they are because they got this way, not because they always were or have to be or will always be this way. The 'things' are both the objects of study and ourselves, the scientists who study them. The two questions are of course not independent. The long-term processes create the variables of the persistent systems. The processes that keep aspects of systems intact also change other aspects and eventually change the identities and connections among the parts. The self-regulating processes not only preserve the equilibria but also the directions of change of equilibria. Equilibrium is a form of motion, a relatively stable relation among changing things.

Revitalising science

At present science is being pulled in opposite directions. On the one hand, economic pressures are undermining the traditional - always exaggerated but none the less real - relative autonomy of scientists. The single-minded concern of governments to cut costs and to privatise is shifting control of science as a whole, and the conditions of work of scientists, to administrators who see science as an industry like any other industry and scientists as a scientific workforce to be managed like any other workforce. The product of the science industry is knowledge that can become commodities mostly as physical objects but also as services and reports. The economic rationality of the administration encourages the fragmentation of scientific workshops, specialisation, short-term precisely defined goals, decisions based less on intellectual or social necessity and more on marketability and risk avoidance. They manage scientific labour with the familiar devices they use in any industry - a myopic view of 'efficiency', downsizing, use of part time and temporary researchers and teachers, hierarchical rankings that keep the producers divided. Scientists learn quickly to plan research efforts based on criteria of acceptability and fundability, to rush publication to meet the timetables of appointments and promotions, to weigh carefully the costs and benefits of sharing and secrecy.

These trends are in conflict both with the internal intellectual needs of science for a more integrated, dynamic, dialectical outlook, and with the urgency to confront problems too big to face in a fragmented way. A science that is up to the mark would differ from the traditional Euro-North American science in a number of ways:

1. It would be frankly partisan. I propose the hypothesis that all theories are wrong which promote, justify or tolerate injustice. The wrongness may be in the data, its interpretation or its application, but if we search for that wrongness we will also be led to truth.
2. It would be democratic in at least three ways. First, access to the scientific community would be open to everyone with the scientific vocation without the barriers of class, racism or misogyny. Second, the results of science would be available to the whole population in a form that is intelligible and without the secrecy often justified in the name of national security or proprietary rights. Third, it would recognise that science prospers when it can combine the knowledge and insights of institutional science with those of the fanners, patients, and inhabitants of workplaces and communities that make up the 'alternative' movements. This is not quite the same thing as combining professional and nonprofessional understanding, since alternative movements have always been invigorated by professionals who ally with them. The result is a mobilisation of much more of the world's intelligence, creativity, and insight than ever before.
3. It must be polycentric. The centres of world science have shifted historically from the ancient middle east, south and east Asia and Central America to Germany, France, England and now Euro-North America. This monopoly of knowledge has served monopolies of power. It has often resulted in the imposition of foreign agendas on the scientific communities of the third world and has deprived us all of insights that are often less rigid, less fragmented and more dynamic and that arose in societies quite different from our own. Polycentric science must not become a sentimental orientalism or nationalism or deference to the ancient because it is ancient. Rather it must recognise that each social context produces its own pattern of insight and blindness, its own urgencies and indifferences, its own penetrating revelations and built-in confusions. A new global science must share techniques, knowledge and tools, be able to compare and choose, but also respectfully leave room for radically different approaches for facing the unknown.

4. It must be dialectical. The term dialectical materialism has had a bad reputation because of the way it was debased by Stalin and his school. The best dialecticians were eliminated or silenced, perhaps not singled out but caught up among others in a democracy of terror. It was then possible to reduce that rich perspective into a set of rigid rules and apologetics for decisions already taken on other grounds. However, as the most comprehensive self-conscious alternative to the predominant reductionism of cartesian science it has been the starting point for my own research. It offers the necessary emphasis on complexity, context, historicity, the interpenetration of seemingly mutually exclusive categories, the relative autonomy and mutual determination of different 'levels' of existence, and the contradictory, self-negating aspects of change.
5. It must be self-reflexive, recognising that the intervenors are part of the system and that the way we approach the rest of nature must also be accounted for. Thus it has to be doubly historical, looking at the history of the objects of interest and of our understanding of those objects.

This is a programme that runs counter to the prevailing trends in science, education and technology. Therefore it is not only an intellectual challenge but is also a highly political one which requires us to resist the pressures of the new world order. When the world recovers from the confusion that has accompanied the euphoric globalisation of greed, when the certainties of the present moment are once again in doubt, and our species joins together to continue its long quest for justice, equality, solidarity and now also survival, it is just possible that science will be there too, creating, receiving and sharing the knowledge that liberates.

The Edinburgh Medal *is awarded by the City of Edinburgh Council to honour men and* women *of science who have made a significant contribution to the understanding and well-being of humanity. It was awarded in* 1996 *to Richard Levins, for his work on the integration of diverse sciences to create holistic models of population biology and ecosystems, in practical co-operation with farmers, and his lifelong commitment to science for the people.* The Edinburgh Medal *is one of the key events of the Edinburgh International Science Festival which takes place each year around Easter for two and a half weeks.*