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The logic of failure

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Unlike other living creatures, humans can adapt to uncertainty. They can form hypotheses about situations marked by uncertainty and can anticipate their actions by planning. They can expect the unexpected and take precautions against it.

In numerous experiments, we have investigated the manner in which humans deal with these demands. In these experiments, we used computer simulated scenarios representing, for example, a small town, ecological or economic systems or political systems such as a Third World country. Within these computer-simulated scenarios, the subjects had to look for information, plan actions, form hypotheses, etc.

1. Introduction

(*a*) *A famine in West Africa*

Our World, unfortunately, is not exactly bereft of catastrophes. Three years ago, the explosion of the Chernobyl reactor made for a great deal of anxiety and a great many discussions, which are still going on, regarding the extent to which humanity can afford technology, the failure of which has such far-reaching consequences.

Questions like these are, of course, especially salient when, as in the case with the Chernobyl disaster, one is dealing with 'man made' catastrophes rather than natural ones. This case, after all, poses the question of avoidability in an especially urgent manner.

The catastrophe I shall be concerned with now, occurred in West Africa, in the Moro region in the state of Bukina Faso which is shown in figure 1. That catastrophe hardly made any headlines. Twelve years ago a development aid project was begun there with the aim of creating generally better living conditions for the semi-nomadic people living in this region. By sinking deep wells, the available water supply was increased, the pasture areas for cattle were better irrigated, resulting in a sharp increase in the stock of herds of cattle. In addition, the tsetse fly, which had severely infected the cattle with sleeping sickness, had been brought under control. So the Moros ten years later were considerably better off. The development of some important variables of the Moro region can be seen in figure 2.

In the end, herds of cattle exceeded the capacity of the available pasture area; a slight decrease in rainfall led to a food shortage; the pastures were overgrazed, and the hungry cattle destroyed the turf and hence the basis for vegetation: the cattle starved to death, thus giving rise to a famine in the human population, which claimed many lives.

Fortunately, this catastrophe did not actually take place in West Africa, but in an office in downtown Zurich. The cause of the catastrophe was not due to a team of development aid volunteers but an executive of an international computer enterprise. The Moro region merely existed in the form of a computer program and serves us as an instrument for investigating the action strategies implemented by persons in coping with extremely complex, dynamic, intransparent and uncertain systems. I shall now describe these attributes of a system more closely.

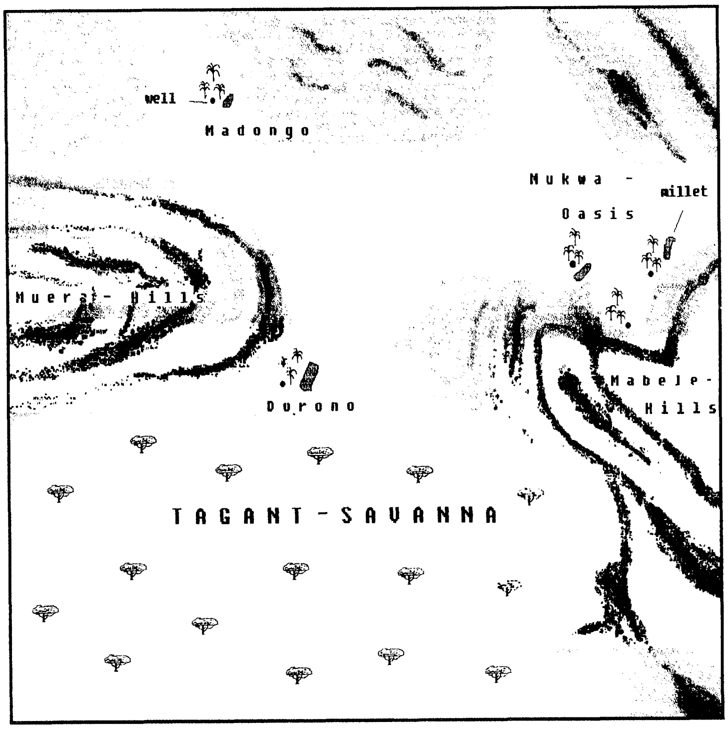

FIGURE 1. The Moro region in Bukina Faso, West Africa.

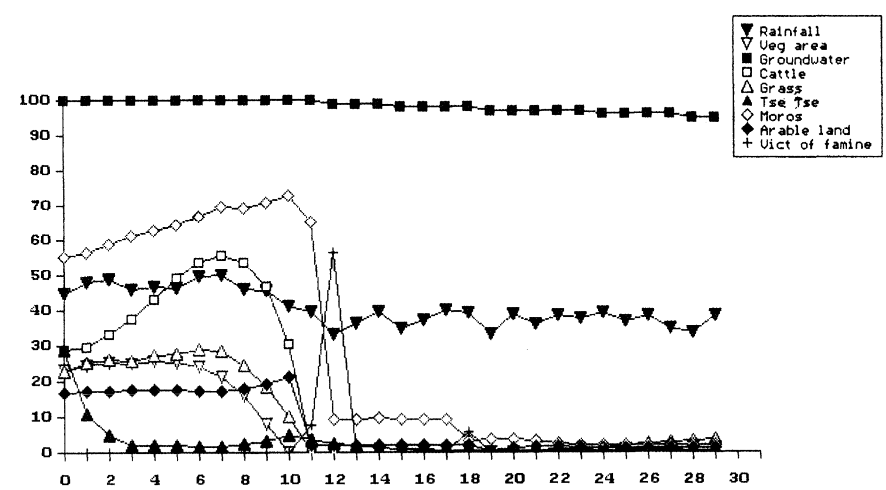

FIGURE 2. A famine in the Moro region.

A system is extremely complex when it consists of a great variety of variables. The Moro system consists of the following variables: population with birth-rate and mortality, cattle stock, ground water, vegetation area, precipitation, area of arable land, millet harvest, etc. All these variables are closely tied to one another, they mutually affect each other and constitute a network of interdependencies, which are shown in figure 3.

The Moro system is dynamic, which means that it develops further, even without interventions. It does not remain stable and waits for interventions like, for instance, a chess board. Because the Moro system is intransparent, many of the variables, for example, the

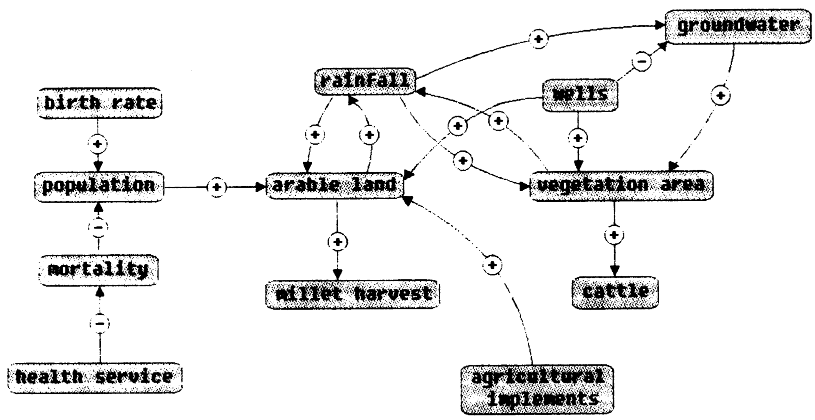

FIGURE 3. Part of the network structure of the Moro system.

groundwater level, defy direct observation. The uncertainty of the Moro system means that the acting subject has no complete knowledge about the system, about its variables and their interdependencies.

For our experimental subjects, the Moro system is a 'dynamic decision problem' (Brehmer & Allard 1986) as the experimental subjects are included in the development of the system. They gather information at a certain point in time, make decisions for particular measures and then execute these measures; they are confronted with the effects of their decisions, are able to gather further data, decide for the same or new measures, and so on. Figure 4 shows the results of the governmental activities of a good subject. It is possible to create positive living conditions for the Moros over a long period of time.

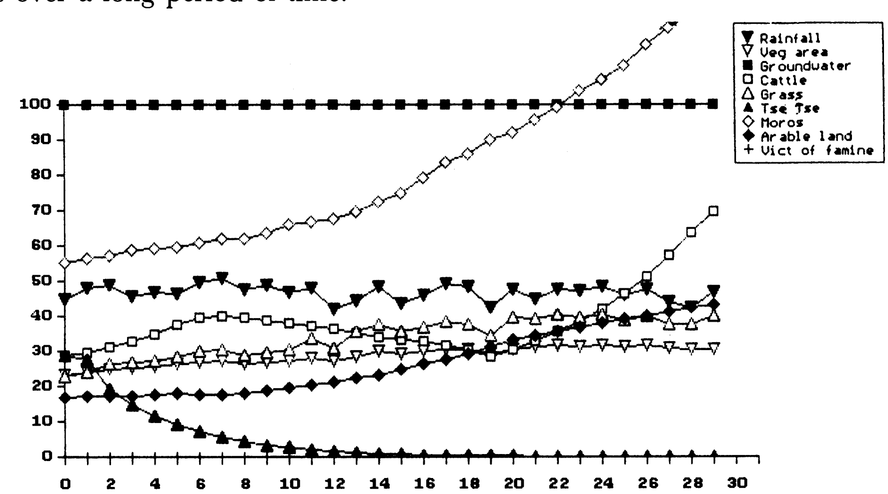

FIGURE 4. Successful governmental activity in the Moro region.

Of course, we do not investigate the behaviour of our experimental subjects in the Moro region with the intention of learning something about the action strategies of development aid volunteers in West Africa. Instead, we believe that action situations, such as those in the Moro region, are in many respects typical of the conditions for action in the rest of the world.

The reason for our experiments with computer-simulated environments is to gain a general insight into the psychology of action-regulation in complex fields of reality. People have to meet

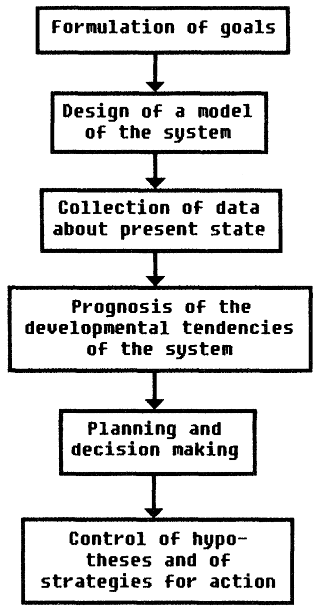

FIGURE 5. Demands of complex action regulation.

various demands in such a situation, which are not at all typical only for the Moro system. Figure 5 shows the tasks that must be performed in coping with such a system.

The first important task is that of formulating goals. More often than not, one has to first get the goals clear in one's mind, as the goals in complex action situations are often given in an indistinct form. One must posit hypotheses on the inner structure of the system with which one is coping. Information must be gathered on the current state of the system at any given time so as to predict the system's developmental trends. Plans and decisions have to be made, and hypotheses and action strategies must be tested. All of these diverse activities must be executed in a manner appropriate to whatever situation is being coped with. When under time pressure, for instance, one should not only plan within a shorter period of time, but differently than when there is plenty of time available. This is discussed later.

2. The reasons for success and failure

What, then, is behind the success or failure in complex action tasks? How do people meet the various demands in a complex action situation of this kind? First of all, differently! In an experiment conducted by Schaub & Strohschneider (1989), we compared the behaviour of 45 executives from large German and Swiss industrial and commercial enterprises with the behaviour of students. Each subject had to try, over a (simulated) period of over 20 years, to improve the living conditions of the Moros. In each year, the subjects were able to ask questions about the (then) current state of the Moros and to make any decisions they wished to. They could buy tractors for the Moros, sink wells, improve medical care, influence trade relations and so on. Figure 6 shows the average results for the executives and the students. On the whole, the executives did far better; they earned, by skilful management, more capital, their herds of cattle were greater, as were their vegetation areas and human populations. There were, accordingly, fewer catastrophes in their simulations.

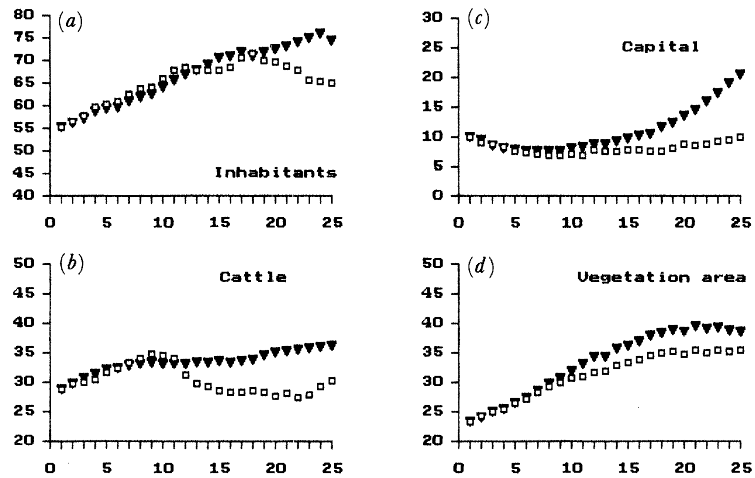

FIGURE 6. The average developments in (*a*), population; (*b*), cattle; (*c*), capital; and (*d*), vegetation, for executives (triangles) and students (squares).

Which mistakes do people make when faced with coordinating complex actions? What are the reasons for catastrophes like the Moro catastrophe described above? We found a great variety of modes of faulty behaviour that were responsible for the failure when acting in such complex situations. Figure 7 presents a rough overview of the various forms of faulty behaviour. Subjects fail, for instance, to get their goals clear and then act according to a 'repair service policy'. They do this by eliminating the obvious errors and solving the conspicuous problems, while disregarding the less conspicuous ones and, of course, failing to take into account aberrant developments that first become apparent in faint symptoms. Subjects fail to construct

insufficient goal elaboration
→ acting according to a 'repair-shop' principle

insufficient formation of hypotheses about the structure of the system
→ neglecting side- and long-term effects

insufficient ideas about the behaviour of the system in time
→ neglecting developmental tendencies of the system

insufficient coordination of different measures
→ 'collision' of measures

'ballistic' action
→ no detection of wrong hypotheses and inappropriate strategies

no self-reflection
→ no 'repair' of wrong hypotheses and inappropriate strategies

FIGURE 7. Modes of faulty behaviour in coping with complex systems.

an adequate picture of a complex, interconnected system. Often enough they do not treat a system as if it were a system, but like an accumulation of disconnected variables that can be manipulated in isolation. In this way, the long term and side effects of their actions remain obscure to them.

Many subjects treat, for instance, the water in the Moro planning game like an inexhaustible resource because they don't realize that drawing water affects the level of the ground water (instances of negative feedback in ecological systems of course intensify such illusions. Stability is generated by such negative feedback, and this may create the impression that a system can 'take anything'. This results in such feedback systems being overstrained and, ultimately, in their irreversible breakdown). Subjects have great difficulty in comprehending the temporal forms of events. Human beings have a strong tendency to react only to the status quo and to disregard developments and their conditions. This is shown in figure 8. The diagram represents the behaviour of two subjects who were given the task of regulating the thermostat of a temperature control unit such that the temperature of 4 °C was attained in a cool-storage unit. The thermostat was a time-delayed system, hence a system with damped sine oscillations, and the subjects had to discover the correct dial setting. As you can see, the subject shown in figure 8(*b*) managed this rather well, while the subject shown in 8(*a*) had more difficulty regulating the system. This latter subject reacted in each case to the immediate temperature state, failed to include the oscillations of the system in the calculations, never learned to do so and therefore always met with failure in regulating the thermostat. (See Reichert & Dörner 1988.)

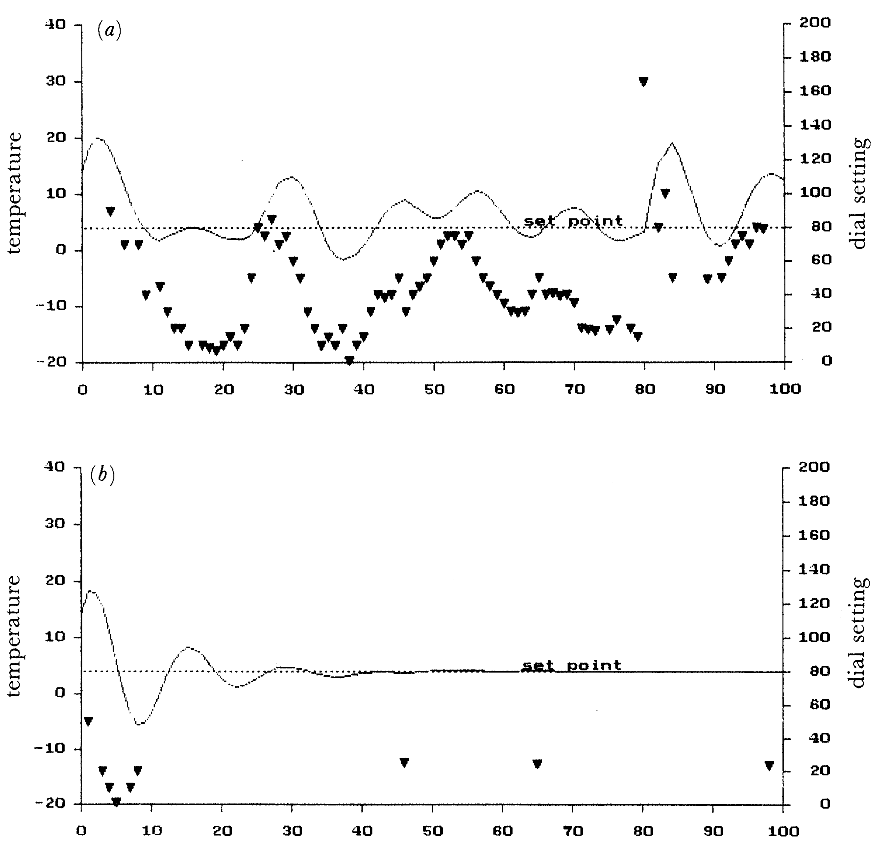

FIGURE 8. (*a*) 'Doer' behaviour and (*b*) 'wait-and-see' behaviour in regulating a thermostat.

Other experiments yielded similar results. The transition from a mode of behaviour focused merely on the momentary state to one which includes the dynamics of a system appears to be extremely difficult. Subjects prognosticate the development of variables by means of linear extrapolation. They assume a linear development even when the situation clearly shows that the development must be nonlinear. They fail to take into account nonlinear developments and especially sudden, 'catastrophic' developments. At the same time, it seems difficult to coordinate various lines of action. Figure 9 shows the successful and unsuccessful subjects in the Moro experiment. You can see that for the unsuccessful subjects the questions and decisions are mixed. This means that the subjects made immediate decisions for each of the states they inquired about. For the successful subjects, however, the question and decision behaviour was not mixed. This means that the successful subjects first gained an overall picture of all aspects of the systems before they began to make their first decisions.

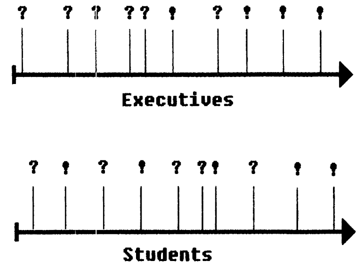

FIGURE 9. Scheme of the sequencing of questions and measures for successful and unsuccessful subjects.

Subjects often act 'ballistically'. They take measures without checking the effects of these measures later. As the effects of measures are usually uncertain, this lies in the nature of complex systems, this is a dangerous error. Crisis situations are especially susceptible for ballistic forms of action, as shown in figure 10. Here, the percentage of checked measures is depicted for an experiment of the Moro type, which was conducted by Reither (1985). You can see that in the first phases of the experiment the experimental subjects checked only between 30 to 50% of their measures. After a 'crisis' in the 10th year, which consisted of an unexpected military aggression of a neighbouring state, the percentage of checked measures

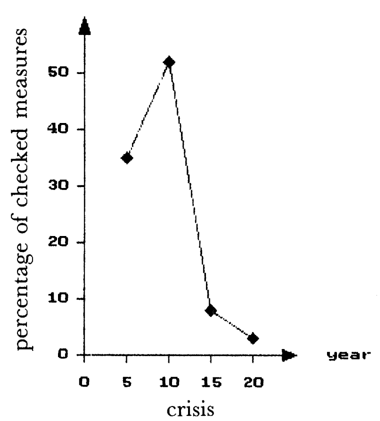

FIGURE 10. Percentage of checked measures in the Reither experiment.

decreased to below 10%. The experimental subjects seemed to exhibit a tendency not to be confronted with the effects of their measures so as to be able to maintain an illusion of competence. Subjects dispense with the self-reflexive analysis of their own behaviour. Subjects' strategies for coping with complex systems are for the most part insufficient, in one respect or another. Self-reflexive examination and critique of one's own way of acting is an essential means of adapting one's own way of acting to the given circumstances. Dispensing with self-reflection is therefore a major error.

3. The background of the mistakes

What is the psychological background of the mistakes just described? If one tries to answer this question, it must be made clear that, while the faulty modes of behaviour described above are inadequate for coping with a complex system, they serve other purposes rather well. Figure 11 shows some interconnections. Many faulty modes of behaviour are expressions of the tendency to deal with the limited resource 'thinking' as economically as possible. Human

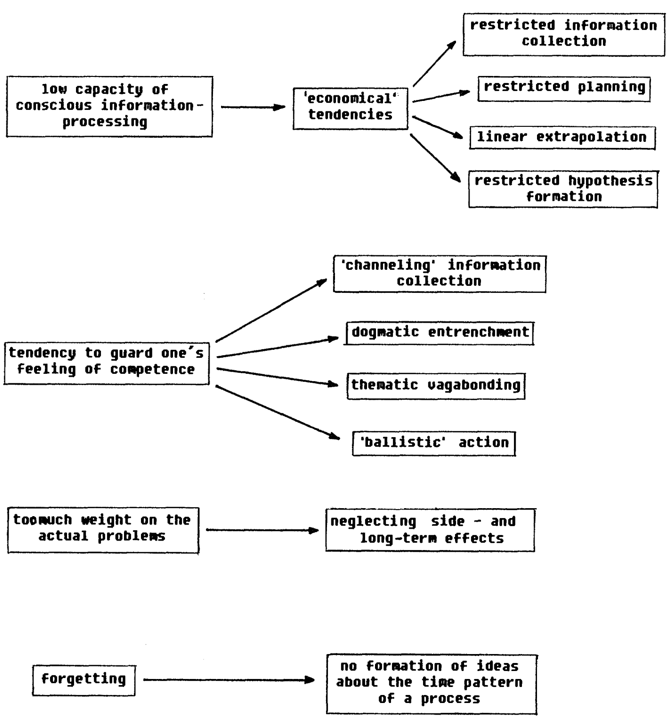

Figure 11. The background of the mistakes.

conscious thinking is neither very fast nor capable of processing very much information per time unit. A tendency to deal with the limited resource economically may therefore make sense. This results, in a certain sense logically, in restricted data gathering, linear extrapolation and restricted hypothesis formation.

Other modes of behaviour arise from the tendency to guard one's own competence. Humans have a strong tendency to guard their opinion of their own competence in acting. To a certain extent this makes sense, as someone who considers himself to be incapable of acting will hardly act. Guarding one's opinion of one's competence is an important motivation. But it can lead to deformations in the thought process. To maintain a high opinion of one's own competence, people fail to take notice of data that show that their hypotheses are wrong. Or they act 'ballistically' and do not check the effects of their actions so as to maintain the illusion of having solved the corresponding problems by means of their action. The underlying reasons for dispensing with self-reflection may also lie in the tendency to avoid looking at one's own mistakes so as not to endanger one's estimation of one's own competence.

Still other modes of behaviour come from the 'predominance of current problems'. Subjects deal with the problems they have, not with those they do not have. Why is this wrong? Why should one bother about problems one does not have? In dynamic systems, the problems one does not have are usually the problems one does not yet have. One's whole attention should not be devoted to the current problems; one must consider possible developments and the possible long term and side effects of the measures taken.

Adapting oneself inadequately to the sequential characteristics of processes may also be attributable to an incredibly simple feature of human data processing, namely, forgetfulness. An important requirement for gaining the correct picture of temporal sequences is having information on the length of time available. If this is not the case, one is also unable to posit hypotheses on temporal patterns. The fact that people forget means that past data are only partially available. This means that there are great difficulties in recognizing the correct form of temporal sequences. A simple means of coping with this difficulty is the 'spatialization' of time. Diagrams of temporal sequences make it possible to treat temporal sequences like 'spatial forms', which are easier to cope with.

4. Strategic flexibility

Why are the executives tested in the Schaub–Strohschneider study less subject to the effects of the factors just stated than the students? There are clues that show that this is because the executives know better 'when to do what'. To a greater extent than the students, the executives have at their disposal a system of local rules (that is rules to be deployed only under certain conditions) for specifically coping with problem situations. And that system of local rules gives them strategic flexibility. Let us for example consider planning behaviour.

(i) 'Make plans before you act!' This is a maxim for acting, which appears plausible. But it is, with this degree of universal validity, wrong.

(ii) Planning means that one forms trial sequences of operators and continues to do so until a sequence that (presumably) leads to a goal is found. Now there are many different ways of planning.

(iii) One can, for instance, plan broadly and attempt to include all possible events and possible results of actions taken in the calculations.

(iv) Or else, one can do in-depth planning and establish one line of action from the very beginning. This is risky, as one necessarily has to disregard the side effects and ramifications of the development.

(v) Or one can completely dispense with planning and put one's trust in finding the right measure in a given situation.

Which of these different forms of action preparation is right in any given situation depends on the circumstances. If there is a lot of time pressure and if otherwise everything would be lost, it is reasonable to do some risky planning and 'stake everything on one card'. The probability of losing out is great, but there is simply no time left for behaving differently. If one did nothing at all, everything would be lost anyway, so it is reasonable to prepare at least one action alternative. In a situation in which time pressure is not predominant, it is a better idea to do 'broad' planning and to take as much as possible into consideration. If, however, the environment in which one has to act is chaotic and its laws unknown, one should not plan at all, as it would be a waste of time. It will all happen differently than planned, anyway.

Even if all the operations in the given environment are reversible and any mistakes made are easily undone, it makes sense to do little planning and to act instead. Whether one should plan and how one should plan depends first, on the reversibility of the operators in the given domain of reality, and secondly, on the predictability of the events and ultimately on time pressure. Thus, with regard to planning, the strategic flexibility of thinking consists of one taking into account the features of the situation of action just mentioned and doing broad or in-depth planning, or no planning whatsoever.

The executives are able to judge when which mode of behaviour is appropriate and when it is not. The unsuccessful subjects do not display a sufficient 'fit' between what kind of thinking they employ and the situation. The successful subjects, on the other hand, adapt their thinking to the situation. The good subjects display a greater degree of strategic flexibility than the bad ones.

The reasons we have cited in this paper for the failure of actions in complex and dynamic domains are extremely simple. At the same time, they are very general, and probably one always has to reckon with their effects when people are dealing with complex and dynamic systems. Is it possible to learn how to cope with uncertain, complex, and dynamic network systems? Is it possible to learn how, in general, to cope with uncertainty and complexity? Of course it is possible to learn how one has to act when dealing with the specific demands of the Moros. But the point is whether it is possible to adapt oneself, one's behaviour and thinking, and planning to the possibly contradictory demands of ever changing situations. It is therefore not a question of concrete modes of behaviour, but of whether it is possible to learn to take into account the conditions that show when a concrete mode of behaviour, that is, when this or that form of planning, data gathering, prognosticating, etc. is correct. The fact that this can be learned can be readily seen in the differences between executives and students reported earlier. In terms of pure facts on the Moros, the executives do not know any more than the students. But they know how to adapt themselves to this kind of situation. And they appear to have learned this in the course of their professional lives.

It is possible to learn strategic flexibility. I believe, however, that it is difficult to teach it. It is not a matter of learning a few readily grasped general principles, but of learning a lot of small, 'local' rules, each of which is applicable in a limited area. The point is not to learn how to drive a steamroller with which one can flatten all problems in the same way, but to learn the adroitness of a puppeteer, who at one time holds many strings in his hands and who is able to adapt his movements to the given circumstances in the most sophisticated ways.

I thank Kristin Härtl for many valuable remarks and also Andy Libby for help with the translation of the text.

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Discussion

P. Nixon (*Charing Cross Hospital, London, U.K.*). Medical education appears to be designed to reduce the ability of doctors to deal with uncertainty in an environment that is turbulent, uncertain and changing at an unprecedented rate. Their withdrawal, and their inability to provide for the needs of people in such a milieu might be one of the causes of the flight to alternative and complementary medicine.

D. Dörner. I am not familiar with medical education in the U.K., but the reply I am about to give seems to be true of German medical education, and indeed education in general. Training and education tends to provide only standard measures and operations; it does not prepare people for coping with genuine uncertainty or with any kind of situation where standard methods are inappropriate. Such education is always simpler to provide. Indeed, it seems to me very difficult to educate people, by formal means, how to cope with the new and the unknown. On the other hand, our experiments seem to show that people can learn to cope in such situations through successive computer simulations, and perhaps this suggests the possibility of a new kind of training based on computer simulation of tasks with many indefinite and unpredictable variations.

S. D. Rosen (*Charing Cross Hospital, London, U.K.*). Selection, in two respects, is a process that could be applied to Dr Dörner's fascinating study of the relative competence of business executives and students at directing the Moro economy and the executives prowess. My first question is, since we can assume that the business executives are good at business (at least to the extent of being known professionally as business executives), might it not be the case that business executives are selected for their possession of the sorts of skills and attributes that would be effective for running an economy? These skills might well include flexibility, projective planning, etc. A second point (to me one of greater interest) is how far could one use the testing process of the Moro model for the selection of persons with fitting aptitude to professions such as clinical medicine or professional politics? The differentiation of people with these qualities from those solely competent at acquisition of book knowledge could prove invaluable.

D. Dörner. I cannot answer the first question as I don't know how the executives in our experiment were selected, but one should stress the fact, that this Moro problem was not an economic one and therefore skills and attributes, which are effective only for running an economy, would not be very helpful. The executives must possess some rather general skills (which they might have learned when coping with economical problems). The second point is of great interest and importance to me. It might be, that computer simulations of that Moro type might prove to be very effective for the selection of people for positions where it is necessary to cope with uncertain and complex situations.