USING SIMULATION TO STUDY COMPLEX PROBLEM SOLVING

A Review of Studies in the FRG

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A new paradigm for studying problem solving and decision making under uncertainty requires attention not only in the academic but also in the public forum: the use of computer-simulated scenarios, with which people have to interact and which should be controlled. This article reviews current research topics in German-speaking countries.

Complex problem solving, in modern terms, was first discussed by Dörner, Drewes, and Reither (1975) and given a specific content: It concerns peoples' ability to deal with unknown scenarios, in which they have the delegated decision authority for a certain number of simulated situations. The establishing of the project "Systemdenken" (systemic thinking) by the "Deutsche Forschungsgemeinschaft" (German research fund) in 1975 guaran-

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teed the financial and staffing framework for the work on this topic. Besides Dörner and his associates Kreuzig, Reither, and Stäudel, Lüer and his associates Hesse, Putz-Osterloh, and Spies had contributed publications that furthered these "new" ideas: the replacement of the traditional paradigms for problem solving through various systems of computer simulation. But even by the end of the seventies there was little more to show than short reports (such as Dörner, 1979; Dörner and Stäudel, 1979; Kreuzig, 1979a, 1979b; Reither, 1979). This changed in the eighties: One can truly speak of a "wave" that resulted from the small-scale system TANALAND and the following large-scale system LOHHAUSEN (Dörner, Kreuzig et al., 1983). The present state of research already makes a review necessary, which the reader will find in the following section. Subsequently, considerations concerning a systematization of the subject matter will be discussed.

PROBLEM SOLVING WITHIN COMPLEX COMPUTER SIMULATED DOMAINS OF REALITY

The studies discussed in this review were required to meet the following criteria:

(1) A simulation-system concerning a certain sphere of reality is available with at least two mutually exclusive independent variables.
(2) Subjects are confronted with this simulation-system. The instruction demands from the subject the active control over this system.
(3) The subject's overt behavior is observed with regard to this simulation system.
(4) The study uses a computerized (as opposed to manual) simulation. This is a somewhat "arbitrary" criterion to limit the number of studies reviewed and does not have any bearing on the experimental results surveyed.

The arrangement of the material follows my intention to emphasize the developmental aspects of this branch of research. It starts with the system TANALAND, which reached its climax as LOHHAUSEN. These were followed by TAILORSHOP and a question about the connection between test intelligence and problem solving. Finally the manifold new and further developments have to be considered, which split the "traditional research" into a variety of spearheads, varying in intention and rudiments.

THE FIRST IMPULSE: TANALAND

The TANALAND system (see Dörner, 1975; Dörner et al., 1975; Dörner and Reither, 1978) was the earliest simulation study published in Germany. The ecosystem of an African landscape is simulated, with various flora and fauna as well as human groups—the "Tupis" and "Moros," who live by cattle and sheep farming. The 50 or more system variables were associated through a complicated process of "positive and negative feedback." The 12 subjects in this exploratory study—students with a mean IQ of 122—each were to assume the role of a technical agronomy adviser to improve the living conditions of the native population. But

> the results showed, that the subjects almost always destroyed the—originally stable—state of the variables of the simulated community and often created catastrophic situations. In spite of a large number of actions and decisions, one could see that many subjects, in time, tended to concentrate on just a few major commitments and weren't willing to vary these. This fact, paired with the obvious inability of the subjects to cope adequately with the exponential growth and the connectivity of the variables, shows the main deficit of the subjects' behavior in the complex reality-spheres we created [Dörner and Reither, 1978: 527f].

The observed failures mirror deficits of a more general nature. Thus it is clear that "the subjects did not possess enough cognitive ability to be able to cope with complex systems"—according to Dörner, Drewes, and Reither (1975: 340). The controversy of this opinion was carried into the public domain, where the press published headlines such as "Environmental and ecological problems overtax the thinking powers of voters and politicians." The failure of "linear thinking" was proposed. In the realized systems, which were described in terms of such features as dynamics, complexity, connectivity and opaqueness, thinking in the form of causal networks should be considered.

THE CLIMAX: LOHHAUSEN

If TANALAND was the first step in the direction of complex study material, then LOHHAUSEN was its expansion. The simulated reality now covered over 2000 variables—a small city called Lohhausen, in which the subjects took the role of the mayor. LOHHAUSEN is probably the most famous of the simulation systems mentioned here. Dörner, Kreuzig, Reither, and Stäudel's (1983: 13) comprehensive monograph introduces the work on this unique study—a five-year project—in three sentences:

> The following report states the results of a relatively long-term psychological experiment. We tried to find out something about the conditions and forms of actions in ambiguous and complex situations. For this we systematically observed 48 subjects over a relatively long period and processed the manifold results of these observations.

LOHHAUSEN, originally the name of the simulated town, has since become the name of a research program characterized by a deepening of cognitive psychology through new paradigms of problem-solving research—paradigms which, as opposed to the traditional types of problems such as mind games or mental exercises, essentially show up the characteristics of complexity and uncertainty (see Dörner, 1981). The authors consider their simulation program of the small, fictional community of Lohhausen to be an example of this. The subjects who were to take over the role of the mayor of Lohhausen, should "take care of the future prosperity of the town over the short and long term," that is, over a simulated 10-year period, split into 8 two-hour sittings. This was a task that, taking the program complexity into account, didn't come easily. But the experimenters were confronted with complexities as well: Approximately 100,000 data points per subject resulted, from which one hoped to successfully separate the important from the trivial and the accidental from meaningful information.

The analysis of the findings—with a few exceptions, such as the case studies of selected experimental subjects—was based upon aggregated data. First they agglomerated the objective and subjective measures of the problem-solving quality to a single "General Quality Criterion," which makes the splitting of the sample into two extreme groups (N = 12) of good and bad problem-solvers possible. It showed that different variables in the LOHHAUSEN system (such as earnings of the industry, funds of the towns, stocks of the bank, production and trade data, number of inhabitants and rate of employment) developed more detrimentally when worked on by the bad subjects as opposed to the good subjects. But the "good subjects" were not what their designation suggests: System experts (the experimenters) achieved even higher values in some variables.

The behavioral effects were less interesting than the connected thought, planning, and decision processes: Besides formal characteristics (e.g., the frequency and consistency of decisions) and content biases (e.g., "financial situation of the watch factory") of the experimenters' "gross protocol," there were interesting references in the "think-aloud protocols," which the subjects were encouraged to produce. The connection between problem solving quality of the subjects and their test intelligence should be high to be in accordance with the construct validity of intelligence: "[We expected] *a high correlation between the general quality criterion and intelligence test ability*" (Dörner et al., 1983: 304).

The data didn't support this hypothesis though: Neither Raven's Advanced Progressive Matrices (APM) nor Cattell's Culture Fair Intelligence Test (CFT) correlated substantially with the solution quality, but what correlated was the experimenters' spontaneous judgment that a "subject makes an intelligent impression." The authors were correct in discussing the shortcomings of classical IQ tests (e.g., not taking information *search* into account), but did not take a possible interpretation of their findings into account: The possible lack of reliability of their problem-solving measure. It is known that intelligence tests when used repeatedly produce homogeneous results; though the problem of measurement errors with problem-solving measures is not discussed. Also the sample limitations (students with a restricted range of IQ scores) should not be ignored when interpreting this result.

Further findings were connected with personality characteristics and their relation to solution quality. In this connection the construct "self-confidence" has to be given a special mention; it had a strong positive relation to complex problem-solving and was introduced to set off "the total failure of intelligence tests." Also prior knowledge (as revealed by different branches of study) was not a significant predictor of success.

The condensed theory of the comprehensive study is made up of the listing of elementary information processing methods for dealing with complex problems, such as, for example, component and dependence analysis as well as sub- and superordination processes. The construction and pursuit of partial objectives by a subject are subsumed under the familiar intentional operation model (see Dörner, 1982, 1983c). Based upon the emotional embedding of cognitive processes (Dörner, 1983a; Dörner, Reither and Stäudel, 1983), the *intellectual emergency reaction*—a quick and general reaction of the cognitive system to unspecified danger situations—can be brought into connection with the actual competence of the actor. Self-confidence can be used as an indicator for heuristic competence, which refers to the ability "to be able to create adequate ways of dealing even with unknown situations" (Dörner, Reither, and Stäudel, 1983: 436; Stäudel, 1987). Central to the theory is the concept of *control*: Control competence guarantees action in uncertainty; loss of control leads to the negative emotional consequences, which override problem-solving thought.

LOHHAUSEN not only stands for a new field of research in cognitive psychology, it also represents an appeal against the prevalent "analytical procedure" in scientific endeavor (see Dörner, 1983b). The examination of the highly complicated cognitive system "mankind"—following Dörner—cannot be pursued using strictly experimental means, since the isolation of a few chosen variables in a laboratory can say little about the "normal" working of processes, which are interactively embedded within other variables. The demand for an intensified "collecting of beetles and butterflies," that is, the exact description of the observed phenomena, goes hand in hand with the search for an "overlapping concept framework concerning the complete workings of the psychic system" (Dörner, 1983b: 24). Not only because of this aside concerning the theory of science does LOHHAUSEN embody the flair of the breakaway: The break with the classical methods of strict experimental laboratory research, forgotten the many "l'art pour l'art" investigations, the pursuit of "everyday" problems.

It is clear that this turnaround will not be appreciated by every member of the "scientific community" (see the critical comments from Eyferth et al., 1986; Funke, 1984b). The following chapter will give some examples of studies with the new paradigm. But first a few remarks, mainly concerning the failure of classical intelligence tests in predicting complex problem-solving measures.

INTELLIGENCE AND THE TAILORSHOP

TAILORSHOP (see Putz-Osterloh, 1981b, 1983b) is a miniature system in which subjects take over the running of a tailor shop: Through the process of purchasing raw-materials and the preparation of production capacity in form of workers and machines, shirts are to be produced and sold at a profit. The aim of the pilot-study is described by the author as follows:

> The purpose . . . is to describe and examine the *sine qua non* of complex problem-solving and of intelligence test tasks, and which problem-solving processes are used to surmount these requirements. Besides, complex problems should be more strongly equated with everyday problem situations than intelligence tests presently are [Putz-Osterloh, 1981b: 80].

In a complex problem, as opposed to IQ-test items, the construction and derivation of problem-solving objectives require a choice of actions leading to the achievement of the goals and the active search for information about relevant system variables.

We will not discuss the findings of the pilot study here. An antecedent study by Putz-Osterloh and Lüer (1981) that was published the same year and that had the same format as the pilot study, tested the hypothesis of the connection between test intelligence and problem solving through a comparison of a *transparent* with a *nontransparent* condition (N = 70 student subjects). These two experimental conditions were the presence or absence of an illustration, which presented the connections between the system variables (a controversial discussion on transparency can be found in Putz-Osterloh, 1983a, and Funke, 1984a).

Under only the transparent condition the authors found a statistically significant correlation between problem solving and IQ. They interpret this result as a critique of normal intelligence tests, in which transparency is high. They argued that "everyday experience makes it plausible that 'real' problems are rather intransparent and highly complicated and therefore decisively demand behavior which cannot be measured by intelligence tests." (Putz-Osterloh and Lüer, 1981: 332).

This argument—it is to be found in many of this workgroups' studies (e.g., Dörner and Kreuzig, 1983)—has not remained unchallenged (see Funke, 1983b; Hussy, 1985; Jäger, 1983, 1984; Tent, 1984). In a more recent study, Putz-Osterloh (1985b) discriminates between "problem-solving intelligence" and "test intelligence," assuming an overlap but not a complete congruency of the respective performance determinants. With this point of view the discussions on the relation of problem-solving and intelligence will become less important. This doesn't mean that the simulation system TAILORSHOP has thus been fully discussed. Critical remarks concerning details of this program can be found in Funke (1986: Ch. 4).

FOLLOW-UP STUDIES

It is not easy to arrange the follow-up studies systematically, since the research themes ask divergent questions and the chosen domains of reality are very heterogeneous. Even the simulation systems can be compared only superficially. Table 1 gives a survey of the simulation programs used.

The number of variables were used as a grouping characteristic, a criterion that is sometimes seen as an essential indicator of complexity (see the critique of this point of view by Funke, 1984b). How little light this criterion sheds on the matter is shown by the question of the subjective working of this parameter: Is a system with 12 variables only half as difficult as one with 24? Is a system with 2,000 variables 100 times harder than the latter? Is there a nonlinear (logarithmic?) connection between perceived difficulty and the number of variables, or rather other evidential system characteristics? These questions cannot be answered here; in the next section we will give only a general introduction to relevant papers.

TABLE 1
Overview of Simulation Systems

Name[a]	# of vars	References
Systems with up to 10 variables		
COLD-STORAGE DEPOT	6	Reichert, 1986; Reichert and Dörner, 1987
ECOSYSTEM	6	Fritz and Funke, 1988; Funke, 1985
GAS-ABSORBER	6	Hübner, 1986, 1987
HAMURABI	8	Gediga, 1983; Gediga, Schöttke and Tücke 1982, 1983; Gediga, Schöttke and Tücke-Bressler 1984; Schöttke and Gediga 1982
MINI-LAKE	6	Opwis and Spada, 1983, 1985; Opwis, Spada and Schwiersch, 1985; Spada, May and Opwis, 1983
MOONLANDING	3	Funke, 1981, 1983a; Funke and Hussy, 1984; Granzow and Hussy,1986; Hussy, 1985; Hussy and Granzow, 1986; Thalmaier, 1979
PORAEU	8	Preussler, 1985; Preussler and Dörner, 1985
SIM002	10	Kluwe and Reimann, 1983; Reimann and Kluwe, 1983
WORLD	4	Eyferth et al., 1982
Systems with up to 100 variables		
DAGU, DORI	12	Hesse, 1982; Putz-Osterloh, 1985a, 1985b; Reither, 1981
EPIDEMIC	13	Hesse, Spies and Lüer, 1983; Spies and Hesse, 1983
MORO	49	Putz-Osterloh 1985a, 1985b; Strohschneider, 1986; Stäudel, 1987
SIM003	15	Kluwe, Misiak and Reimann, 1984; Kluwe, Misiak and Schmidle, 1985; Kluwe, Misiak, Ringelband and Haider, 1986; Misiak and Kluwe, 1986
TAILORSHOP	24	Funke, 1983b; Putz-Osterloh, 1981b, 1983b, 1985a, 1985b; Putz-Osterloh and Lüer, 1981; Roth, 1985
TANALAND	54	Dörner, 1975; Dörner and Reither, 1978

(continued)

TABLE 1 Continued

Systems with more than 100 variables		
ENERGY SUPPLY	>2000	Rost and Vent, 1985; Vent, 1985
LOHHAUSEN	>2000	Dörner, Reither, Kreuzig and Stäudel, 1983 (vicarious for many articles)

a. The name of the system may be the translation of the German title of the scenario as it is introduced in the text.

STUDIES IN WHICH PERSONALITY CHARACTERISTICS PLAY A CENTRAL ROLE

Under this heading we subsume papers wherein attributes of the simulation program are accepted as given and attention is oriented toward which personal characteristics are to be made responsible for the observed system effects (generally: successful versus unsuccessful manipulation). Besides the influence of test intelligence, the interest here lies in personality characteristics of the problem-solver such as self-reflection, motivation, differentiation of semantic memory, and self-confidence. Statistical analysis of language usage (Roth, 1985), examination of eye movements (Lüer et al., 1984) or the influence of political values (Kühle and Badke, 1985) mark further questions in this region. The following review is in alphabetical order by the name of the simulation system (see Table 1).

COLD-STORAGE DEPOT. Reichert (1986) used in her study a COLD-STORAGE DEPOT that subjects had to control by means of a steering wheel, with which the temperature of the depot could be changed in an unknown way. The subjects, 54 students, each had the opportunity of 100 interventions. They were told that the automatic steering was defective and that human control was necessary in order to prevent the food from being spoiled. The results showed that only one-fifth of the subjects ran the depot successfully. The main difficulty was the time-delay of the nonlinear function: Some subjects recognized this delay and planned their action adequately in time, and other students changed their interventions immediately after feedback. Some of the "good" problem solvers could not articulate the rules they were effectively following. Reichert and Dörner (1987) developed what they call a "simulation of the simulation," that is, a psychological simulation model for the handling of the simulation game. Their "generating system" produced a synthetic

behavior that could not be distinguished from the behavior of real subjects.

DAGU. Reither's (1981) study simulated the climatic ecological and ethnical situation of a fictional African developmental aid area called DAGU, comparing 12 development-aid workers with between 6 and 8 years of practical experience in African or Asian third-world countries (experts) with reference to the problem situation to 12 subjects who are about to begin their first mission in developmental aid (novices). What the subjects had to do was to create better living conditions for the people of DAGU and to increase their population, whereas they had to prevent overpopulation. Seven operational areas (i.e., with possibility for inventions) were designated (food, animal fodder, birth-control, medical supply, preventive actions against the tsetse fly, setting up of irrigation projects, and sale of produce). The results of the study, in which the subjects worked in groups of three, showed that the experts and novices thought and acted differently: the novices thought more in causal chains than in causal webs, meaning that they did not take side-effects into their deliberations, but thought of "straight-on" main effects. The novices showed more thematic jumps and made more "metastatements." The hallmark of experts is their blind coping; that is, they come under all circumstances to conclusions, thereby demonstrating a continuity of action under every condition. The results also show that even experts aren't able, for instance, to stabilize the critical variable "population size."

DORI. The program DORI simulated the living conditions of a nomad tribe in the Sahel region whose livelihood depends on cattle rearing. In Hesse's (1982) work this is the semantic version, which is compared with the results of the version in which the variables are designated by Latin letters (nonsemantic, abstract version). The semantic factor was crossed with a factor transparency, the two stages of which were the presence or absence of a graphical display of the connections between the variables. A total of 120 students, 30 per experimental condition, were used as subjects. The discovered differences between good and bad problem solvers suggest a difference in the subjects' strategy based upon the semantic cover story: whereas notes were more heavily consulted under the abstract conditions ("external memory"; see Muthig and Piekara, 1984; Muthig and Schönpflug, 1981), the subjects of the semantic group asked a larger number of pointed questions and organized their actions better. Only under the abstract condition was there a positive connection between intelligence test scores and problem-solving quality. This result is in line with the previously discussed correlation between transparency and IQ.

EPIDEMIC. The program EPIDEMIC corresponded to the DORI system with the exception of newly chosen semantic and new individual connections. The subjects in this study by Hesse, Spies, and Lüer (1983; see Spies and Hesse, 1983) were to take charge of the health authority of a small town in the aftermath of an epidemic. Their decisions were supposed to reduce the number of illnesses. The subject had the choice between seven possibilities of intervention. The EPIDEMIC study's main area of concern was the effect of personal distress, which was realised by simulating two kinds of epidemics, each of which was presented to groups of 30 students. Whereas a reduced level of distress was supposedly induced by a simulated influenza epidemic, a higher level of distress was to be induced by a dangerous smallpox epidemic. In both cases the same structural equations were used; only the semantic labels of the variables were changed. The findings of the experiment point out the effectiveness of this variable upon the problem-solving quality: the highly distressed students obtained higher quality values, worked harder, took more effective actions, and recognized effective measures more readily. It was not controlled whether the subjects' knowledge of influenza was more differentiated than their knowledge of smallpox (which is much less familiar among students).

HAMURABI. HAMURABI is the name of the absolute ruler of the agrarian state of "Summaria," which was the subject of Gediga's (1983) as well as Gediga, Schöttke, and Tücke's (1982, 1983; Gediga et al., 1984; Schöttke and Gediga, 1982) simulated studies. The subjects (N = 28 psychology students) are given the task to keep alive as much of the population of Summaria as possible by using four sequential decisions (purchasing and selling arable acreage, deciding the area to be sown with corn, and determining the quantity of food required by each member of the community) in two trials each lasting a simulated 30 years. Random variables were taken into account. The results show that on the one hand problem situations with an exponential change in time were mastered by only a few subjects; on the other hand the hypotheses of many subjects were in accord with the complex problem situation and led to better performance.

MORO. Strohschneider (1986) as well as Putz-Osterloh (1985a, 1985b) and Städel (1987) used the scenario MORO, which simulated the situation of a small nomad tribe in the southern Sahara. Their studies dealt with the question of just how far this research instrument could be used to gather stable data and what evidence for the external validity of this data could be found. Concerning test-retest stability Strohschneider comes to the conclusion that behavioral indices (e.g., the number of questions posed) show a higher reliability than measures of the systems condition (e.g., the number of starving people). From an exhaustive debriefing of the subjects Strohschneider reaches conclusions concerning the validity of the MORO research situation: Subjects perceived the demands on their problem solving ability in the simulated scenario as valid in respect to the demands of everyday complex problem solving.

WORLD. Eyferth et al. (1982) examined the coping possibilities—the "genesis of handling competence"—in a novel situation. A computer simulation called WORLD was used as research instrument. This WORLD existed as a series of pictures on a screen, upon which a few objects could carry out computer-controlled maneuvers and could move or interact with each other according to fixed rules. The observer can use the keyboard to interrupt and to become actively oriented. His task is to understand the rules and manipulate the objects toward a certain purpose (p. 2ff.).

Four numbered squares can move in various ways that change after collision. The observer can (1) vary the speed with which the squares move over the screen, (2) change the squares' direction of movement, and (3) stop the system. The results of this exploratory study gave hints that subjects gradually construct a system representation and connect it to existing schemata.

STUDIES IN WHICH SITUATIONAL CHARACTERISTICS PLAY A CENTRAL ROLE

Subsumed under this heading are works which systematically deal with the influence of certain simulation program characteristics as potential causes for behavioral effects.

ENERGY SUPPLY. The "Energieversorgung" (ENERGY SUPPLY) of private households in the Federal Republic of Germany is simulated in a large-scale system by Rost and Vent (1985; see also Vent, 1985), in which individual energy choice preferences are projected over time and space. The authors were concerned with the effect of various presentation and feedback forms that stimulate certain ways of thinking (for instance analytical or holistic thinking). In one condition they presented the systems data numerically and in the other they present them graphically. The results tend to support the superiority of a visual-holistic way of thought as was measured by the quality of decisions.

GAS ABSORBER. A "GAS ABSORBER" with one input variable and three states was simulated by Hübner (1986, 1987). His subjects were confronted with one of two different learning conditions, which showed no differences with respect to the quality of control (measured as distance from a given objective point). A significant contribution came from the distance to the goal at the beginning of the intervention: if the goal could be achieved in two steps, less input error was made than if the goal could be achieved in three steps. The results were consistent with those from manual tracking studies (see Bösser, 1983).

MINI LAKE. The ecosystem "MINI LAKE" was used by Opwis and Spada (1983, 1985; see also Opwis, Spada, and Schwiersch, 1985; Spada, May, and Opwis, 1983). A biological population model (with isolated as well as integrated parts) with system characteristics that were chosen on theoretical grounds was selected for this purpose. The subjects were to learn about conditions of change within the framework of the model and to build up their knowledge so that they could make predictions about future conditions and, given precisely designated objectives, take adequate action. The WEIV-paradigm (see Spada, Reimann, and Häusler, 1983) was used to register the complex process of hypothesis construction and modification, information collection, weighting and evaluation, choice ("*W*ahl") of information, expectation ("*E*rwartung") of the state of the variable, communication of information ("*I*nformationsvermittlung") by the experimenter, and utilization ("*V*erwertung") of this information. Using fish stock as an example, a WEIV sequence could have the following appearance:

(W): Choose an origin for the fishstock population in the year k.
(E): Make a founded estimate of the fishstock population in the year k + 1.
(I): Gather information about the true fishstock population in the year k + 1.
(V): Generate or change a hypothesis concerning the supposed functional connection.

Opwis, Spada, and Schwiersch (1985) emphasized that, as opposed to the "classical" methods, (1) a sound model of the research situation should be available, (2) the dynamic process of the variables should be shown and not only be concerned with the presentation of system data of beginning and resulting conditions, and (3) the method of data collection should be most carefully chosen. The authors especially emphasized the problematic nature of reliable and valid problem-solving indicators: with unrestricted access to the system, unknown solubility of the given task, and ignorance of the representation of the system within the subject's memory, the experimental examination of thought processes would be made impossible. Opwis et al. therefore used a research plan that allows a high degree of control with respect to these stated aspects. A model based on individual knowledge data allowed the prediction of approximately 80% of the subjects' answers to questions about the system.

MOON LANDING. Thalmaier (1979) in his work with "Mondlandung" (MOON LANDING) took up a central point of criticism on the previous studies of highly complicated systems when he pointed out "that without exact knowledge of the structure of the observed system . . . one cannot generally define scales for the evaluation of the quality of the described controls" (p. 390). Often it is difficult to decide exactly what has been done wrong. It should always be possible to conclude whether or not the run of things has even made a solution impossible. These arguments lead Thalmaier to the conclusion, valid for dynamic problems of a deterministic as well as a stochastic type, that the mathematical description of the problem type (e.g., the simulated system) and an understanding of the systems' properties is a necessary prerequisite for understanding the behavior of experimental subjects. Using MOON LANDING as an example (see also Funke, 1981, 1983a; Funke and Hussy, 1984), Thalmaier (1979: 401ff.) showed several advantageous aspects of this system-oriented analysis:

(1) There is differentiation between winning solutions (open-loop steering: no correction possibilities, a concentration on winning from the time t onwards) and optimal strategies (feedback steering: an optimal path is sought, dependent upon the present situation, compensation for a mistake is possible). Determining these isn't a trivial matter when one is confronted with problems such as the existence of an infinite number of situations or continuous solution graphs, but the choice of optimal strategies can be reduced to standard mathematical problems such as, for instance, the principle of the poltryaginic maximum (see p. 399ff.). This delivers the necessary condition for the optimal solution's existence, though it leaves open the question of whether or not such a solution even exists.
(2) The analytical solution to the moon-landing problem [p. 406] allows the synthesis of an optimal steering program in the form of so-called "bang-bang steering" (first, free fall up to a certain point in the solution space, then a full burn for braking to a soft landing).
(3) The operation strategies uncovered in the repeated presentation of the problem allow the calculation of the individual distance from the optimum and therefore an exact quantification of the progress in learning [p. 411].

The elaborated formal description of these considerations, which will make access difficult to those less well read in mathematics, lead to interesting insights. It thus appeared that the 20 mathematics students who served as subjects were indeed able, during the total of 20 practice landings, to recognize the dynamic aspects of the problem as well as its nonlinear development. Thalmaier (1979) reached the conclusion "that subjects are not overtaxed from the beginning by nonlinear extrapolations" (p. 408). One has to take into account though, that, concerning optimal steering problems, the subjects' identification difficulties relative to the system that had to be steered were paramount. The

successive recognition of the structure of the system through an input-output-analysis had to be done first (see Funke and Steyer, 1985).

In his conception of the paradigm of MOON LANDING, Funke (1981) was mainly concerned with the experimental extension possibilities of this minisystem; like Dorner and his associates he was not concerned about a simulation system as realistic as possible, but rather about the "testing of specific hypotheses and therefore a precisioning of the theoretical assumptions concerning highly complex problem solving" (p. 4). Here paradigms whose theoretically relevant parameters such as problem difficulty can be varied easily are naturally more suitable. In view of the experimental and evaluational techniques, Funke (1981: 19) wrote the following on MOON LANDING:

> On the one hand there are many possibilities for creating systems that are highly complex, dynamic and hard to see through, on the other hand the problem retains its clarity for the experimenter (at least in principle), whereupon the possibilities for an exact quantification of the solution process and its quality exists.

Empirical findings concerning this paradigm came from Funke and Hussy (1984), who presented this problem type as well as a similarly structured one ("Kochen," COOKING problem). They maintained that experience in the required reality area would lead to a better performance and, in the two paradigms used, equal knowledge would result in no performance differences. The subjects were 24 male and female subjects (each assumed to be respective experts in the areas of MOON LANDING or COOKING because of sex-specific socialization). The results in this case, though, did not conform to the hypotheses. The main effects of the experimental conditions "area" and "previous experience" on the dependent variable "quality of problem solving" only reached a weak effect strength, and the expected interaction didn't materialize. Statistical arguments, though, didn't allow an expanded interpretation of this finding. In the modified target approach paradigm Hussy (1985; see also Granzow and Hussy, 1986; Hussy and Granzow, 1986) could show that the problem-solving quality (measured as distance to a target state) decreased as the number of variables increased as well as in the case of nonlinear interwebbing functions or when the transparency of the problem was lowered. He found a significant correlation between test intelligence and problem-solving quality only under transparent conditions with few variables, which the findings of Putz-Osterloh seemed to support.

ECOSYSTEM. The subjects in ECOSYSTEM (Funke, 1985) had to exert influence on the number of insects and leaves and the amount of water pollution by the manipulation of poison, vermineaters, and fertilizer. There were five passes each of seven cycles. The first four courses allowed any amount of manipulation of the system ("knowledge gaining phase") whereas in the last course a stated objective point had to be achieved ("knowledge application phase"). Through the systematical variation of two critical system attributes, "connectivity of the variables" and "degree of time delay," Funke found that both of the examined influences had a large effect on the knowledge representation quality (a subject's diagnosed "mental model" of the system) as well as on the degree to which the aim had been achieved, whereby the time delay effects seen relative to the interweaving effects appeared weaker. Fritz and Funke (1988) could show differences between pupils with minimal cerebral dysfunction and matched controls with respect to discriminatory and integrational abilities in the process of hypothesis development and hypothesis testing.

PORAEU. Preussler (1985; Preussler and Dörner, 1985) concerned herself with a small predator-prey-model called PORAEU. In a prediction experiment, the author crossed three semantic conditions (helpful, hindering, or neither), two prognosis conditions (only robber values or the prediction of robber and swag values) and two presentation forms (with or without curve displays). In the face of more than 20 dependent variables and more than 30 hypotheses, it is difficult to sum up the result of this work in a few words. The main effects of the three factors upon the predictive behavior were insignificant: Individual interactions showed more distinct effects. Based upon an additional examination of response effects the author concluded "that individuals are not able to make predictions concerning exponential development trends" (1985: 84).

SIM002/SIM003. From a critical view of the studies concerning complex problem solving Kluwe and Reimann (1983; see also

Reimann and Kluwe, 1983) derived their concept of the purposeful construction of an abstract system called SIM002:

> With the construction of our system we are less interested in pursuing the aim of simulating reality, rather we want to develop systems, which can be fitted to many experimental inquiries. . . . We think it is convenient first of all to check special inquiries on reduced systems [Kluwe and Reimann, 1983: 6].

The system SIM002 consisted of 10 system variables, whose relations were fixed in a parameter matrix of first order. The system states were displayed in the form of a histogram upon the monitor of a personal computer, and the subjects could change as many of the variables as they wanted at any time by simple manipulation. The task of the problem solver was to reach the nominal value displayed on the screen, whereby the achieved system states were compared with the end condition; the difference determined the quality measure. Concerning the main result of their pilot study, namely the effect of verbalization upon the problem-solving performance, Kluwe and Reimann (1983) reached the following, for certain areas of research in cognitive psychology perhaps fatal, conclusion:

> Through the experiment we were able to prove that with our research method the collection of verbal data had a significant effect upon the performance of the subjects. One can assume that our subjects were very distracted by the verbalizing. As a consequence of the results we reject the collection of verbal data as far as possible [p. 36].

A further development of the abstract system SIM002 was the system variant SIM003 (see Kluwe et al., 1984; Kluwe et al., 1985; Misiak and Kluwe, 1986) in which the number of variables was increased to 15 and the system variables were also arranged into groups. An unrestricted access to the system was followed by a step-by-step confining of the status display. At uneven intervals the subject had to reproduce the previous system states or, rather, anticipate the next ones. A central assumption of this work concerned the postulate of various states of ordered construction of mental models, which were identified in individual studies of longer duration. The authors saw the elapsing complex learning processes under the perspective of "chunk" construction. An ideal intervention into the system with respect to the stated aim could be designated at any time because of the system construction, so the process of learning gain could be clearly described. An increase in proficiency was coupled with a time gain, which (as with chunk building) was open to large individual differences. At the end of a long steering period (200 simulation tasks per subject) the subjects had a verbalized system knowledge with respect to the connections of the variables as well as to the specific qualities of individual variables.

DISCUSSION

The reviewed articles show a spreading interest in research on the topic of control and decision in dynamic systems in German-speaking countries. There are other research fields with related themes, for example from multistage decision making (see Huber, 1985; Kleiter, 1970, 1974) or research on manual control of dynamic systems (see Bösser, 1983) that should be brought into connection with the referred work. Compared to a 10-year-old review on problem solving (Lüer and Putz-Osterloh, 1978) there are major changes in respect to themes and methodology, if one subsumes the reviewed literature under this topic. The role of emotions has been emphasized (see Kuhl, 1983) as well as the role of human error in modern technology, which requires a special sort of problem-solving strategies (Rasmussen et al., 1987).

Groups working on the reviewed topic could be found in Australia (see, for instance, Mackinnon and Wearing, 1985), Canada (see, for instance, Moray et al., 1986), Great Britain (see, for instance, Broadbent and Aston, 1978), Sweden (see, for instance, Brehmer, 1987) and in the United States (see, for instance, Bhaskar and Simon, 1977).

A growing bulk of studies does not guarantee progress in research. The cumulated work may be a solid ground for the development of theories and models, which not only describe but also explain the observed phenomena. Therefore a taxonomy for complex systems is necessary as well as an answer to the question

of which individual competences problem solvers in these environments must possess in order to do their jobs well. The last point implies the structure and amount of knowledge needed as well as the availability of strategies and heuristics for unknown situations. Analogical reasoning may be of interest in this context.

Another point of discussion concerns research strategy. I think that it is by no means a successful approach to develop one complex system after the other without precisely knowing the different research strategies taken by each. In my opinion it would be fruitful to reduce the manifold of systems to some systems that then should be used by different research groups and in different contexts so that results are comparable with another.

Last, it should be analyzed how participation in simulation affects problem solving in "real" life problem situations. This question of validity may help to evaluate the worth of further research in the area of complex problem solving.

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