DYNAMIS review: An overview about applications of the DYNAMIS approach in cognitive psychology

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Abstract

The DYNAMIS review has been designed to provide an overview about applications of the DYNAMIS approach in cognitive psychology. Since the development of computer-based scenarios DYNAMIS, based on linear structural equation systems, has become increasingly popular as a tool for analysing decision making and complex problem solving. Beginning with the role of system size, connectivity, and types of relations in a system (e. g, eigendynamics and side effects) it has been discussed how formal system characteristics may influence the process of complex problem solving. In a second part, essential task demands, i. e. knowledge acquisition and knowledge application, have been specified further with particular respect to their interdependency. Supporting influences as to effective presentation of information and task demands have been suggested in this context: graphical presentation, semantic embedding, structural diagrams and other tutorials, instructed strategies, specific goals, and hypotheses. Research on the impact of problem solvers' habitual intellectual and strategic abilities as well as motivation completed the presentation of the extensive contexts in which DYNAMIS systems have been applied and possibly will be applied to in future research.

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1 General introduction

The use of computer-simulated scenarios in problem solving research has become increasingly popular during the last 25 years (for a representative collection of papers see, e. g., the two editions from Sternberg & Frensch, 1991, and Frensch & Funke, 1995). This new approach to problem solving seems attractive for several reasons. In contrast to static problems, computer-simulated scenarios provide the unique opportunity to study human problem solving and decision making behaviour when the task environment changes concurrently to subjects' actions. Subjects can manipulate a specific scenario via a number of input variables (typically ranging from 2 to 20, in some exceptional instances even up to 2000), and they observe the system's state changes in a number of output variables. In exploring and/or controlling a system, subjects have to continuously acquire and use knowledge about the internal structure of the system.

Research on dynamic systems was motivated partly because traditional IQ tests turned out to be weak predictors in non-academic environments (see Rigas & Brehmer, 1999, p. 45). According to their proponents, computer-simulated "microworlds" seem to possess what is called "ecological validity". Simulations of (simplified) industrial production (e. g., Moray, Lootsteen, & Pajak, 1986), medical systems (e. g., Gardner & Berry, 1995), or political processes (e. g., Dörner, 1987) have the appeal of bringing "real world tasks" to the laboratory. Brehmer and Dörner (1993) argue that these scenarios escape both the narrow straits of the laboratory and the deep blue sea of the field study because scenarios would allow for a high degree of fidelity with respect to reality and at the same time allow for systematic control of influential factors.

2 The Dynamis approach

In everyday life, a number of activities require the regulation and control of processes which consist of quantitative variables (e. g., driving a car, controlling a CAD-machine). Not only technical but also economic and ecological situations require that we first have to understand the system before goal-oriented action is possible. In many sciences, systems with quantitative variables are represented successfully by means of the general linear model (cf. Stevens, 1992). The use of linear structural equation systems as a tool for problem solving research has been introduced by Funke (1985) under the name of Dynamis (which was the name of the first software shell for realising this type of simulations).

How can such a linear Dynamis model be used as a tool for analysing decision making and problem solving? The subject is instructed that she or he has to deal with a system that consists of some exogenous and endogenous variables. The exogenous ones can be directly manipulated by the subject and, thus, can influence the endogenous variables which can *not* be manipulated directly. The general task is (a) to find out how the exo- and endogenous variables are related to each other, and (b) to control the variables in the system so that they reach certain goal values. Normally, these two subtasks of system identification and system control are separated experimentally as two steps of the whole task (see Funke, 1993).

The basic structure of a simple linear Dynamis system, for example, consisting of four

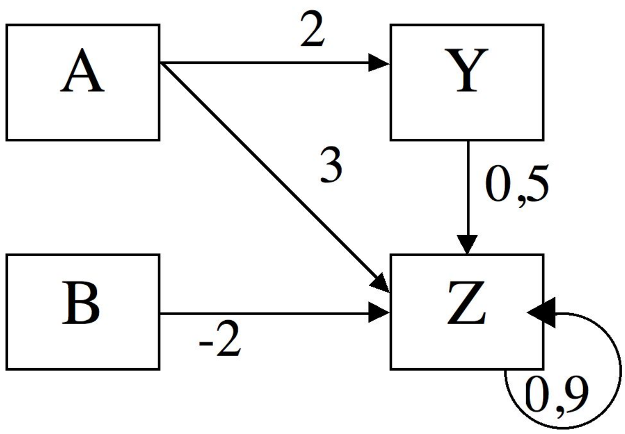

Figure 1: Structure of the simple linear DYNAMIS system with two input variables A and B as well as two output variables Y and Z. Variables are represented as boxes, connections between them are marked by weighted arrows.

variables is shown in Figure 1 (adopted from Vollmeyer & Funke, 1999). Instead of labelling the variables semantically, abstract letters are used. A system which contains semantics from biology can be found in Vollmeyer, Burns, and Holyoak (1996).
In the example system from Figure 1, the variables A and B represent the exogenous variables which have an effect on the endogenous variables Y and Z. The numbers on the arrows represent the weight with which the respective exogenous variables affect the endogenous ones. The system is described formally by two equations (one for each endogenous variable):

$$Y_{t+1} = 2 * A_t \tag{1}$$
$$Z_{t+1} = 3 * A_t - 2 * B_t + 0.5 * Y_t + 0.9 * Z_t \tag{2}$$

In these equations, the indices t and $t+1$ represent the actual state of the system which itself goes on in discrete steps (= periods) on the time axis. From equation (1) it turns out that the value of Y at period $t+1$ can be calculated from the value of A at period t, times two. Similar, in equation (2) the value of Z at $t+1$ can be calculated from the exogenous variables A and B at period t (with weight 3 and -2), from the value of Y at that time (weight 0.5), and from its own value at period t times 0.9. Normally, such a system is presented on a screen where all the variables are shown together with the system's history (for a certain period of time). What is not shown to the subjects is the structure of the system because it has to be discovered by them during the exploration phase.
In some systems, the endogenous variables have effects on other endogenous ones (in Figure 1, the effect from Y to Z), an effect which one might label as "indirect effect" which shows up only in case of manipulating the exogenous variable A. This variable A has itself two effects, one being larger ("main effect" on Z), one being smaller ("side effect" on Y). Also, endogenous variables can influence themselves (in the example shown with variable Z), thus representing an effect one might call "eigendynamic" because of the

constant increase or decrease of this variable independent of other influences. As the reader might imagine, there are many possibilities to construct linear systems with a full range of effects of the kind described above and, thus, making identification and control of such DYNAMIS systems to a hard problem. The two main task demands are knowledge acquisition and knowledge application.

Task Demand 1: Knowledge Acquisition. The term "knowledge acquisition" (system identification) describes a complex learning situation during which the subject has to find out details about the connectivity of the variables and their dynamics. The structural aspects of the system (= connectivity) cannot easily be separated from the dynamic aspects because the system itself can only be analysed interactively over the time course.

In the DYNAMIS situation, this identification problem requires an identification strategy, that is, a certain way of manipulating the exogenous variables so that you can derive from the consequences (in terms of values of the endogenous variables) the causal structure of the system or at least to come to hypotheses about this structure which could be tested subsequently. Identification of system relation can occur in different levels: (a) as identification of the existence or non-existence of a relation, (b) as specification of a direction, (c) as specification of qualitative aspects of this (either positive or negative) relation, and (d) finally as the exact quantitative specification of the weight of this relation.

Task Demand 2: Knowledge Application The term "knowledge application" (system control) describes the situation of applying previously acquired knowledge in order to reach a certain goal state within the system. The goal specifications are normally given by the experimenter.

In the DYNAMIS situation, knowledge application requires two subgoals: first, to transform a given state of the endogenous variables by means of an input vector into the vector of goal values, and second, to keep this goal state on a stable level because in a dynamic system the goal state – once reached – may disappear quickly due to "eigendynamics".

3 Psychological research based on Dynamis

The main aim of the present report is to provide a summary of various applications and research contexts to which computer scenarios of the DYNAMIS family have already been applied or possibly could be of use in the future. Central results and interesting methodology especially of recent DYNAMIS studies are presented to give an introduction to the most relevant findings in the extensive domain of DYNAMIS research.

The overview consists of three parts with subchapters: Part one deals with basic terms and formal characteristics of DYNAMIS systems, i. e. the DYNAMIS algorithm. Experimental studies examining the effects these characteristics have on the process of complex problem solving (CPS) will be discussed. Part two presents findings and theories concerning task characteristics some of which may be implemented in DYNAMIS, other of which refer to the general experimental setting. The third and final part focuses on the person interacting with the DYNAMIS task. Findings on some selected influences of personality such as motivation and intelligence will be discussed in the context of CPS.

3.1 System characteristics

As noted above, system characteristics in DYNAMIS are integrated in the formal algorithm underlying a problem solving scenario and can therefore be termed the "core" of any DYNAMIS program. A very close connection exists between these formal characteristics and the complexity of a system. Asked to imagine a complex system, in the first place one would probably think of a large number of different variables, an even larger number of relations between these variables, the interconnections being hardly detectable and not at all transparent. The more possibilities to interact with a system, the more difficult it will be handled, one might expect. Yet experimental findings about such features are a bit more intricate than just confirming the basic notion that high complexity means low performance.

Three aspects of system complexity will be considered in the following sections: the number of variables in a system, the number of relations and the quality of relations including special types of relation such as parallel or side effects, eigendynamics and effect delays.

3.1.1 The number of variables

The most obvious feature of a CPS scenario possibly is the number of the system's variables. This will also be referred to as the system's size. Numbers of variables range from as few as two variables in the smallest systems to more than 2000 variables in the largest scenarios such as the well-known Lohhausen scenario developed by Dörner et al. (for a brief survey of CPS scenarios in psychological research see Funke, 1992b, p. 8-9). CPS scenarios intended to be more "naturalistic", i. e. closer to problems in real life, usually employ larger numbers of variables whereas in DYNAMIS research, less variables are common. Most of the studies discussed in the present paper applied DYNAMIS systems containing six, seven or eight variables.

Systematic attempts to find out how problem solving is affected by different sizes of DYNAMIS scenarios have been undertaken by Funke (1992a, 1992b). In a study based on the data of 40 participants (students at the University of Bonn) Funke compared problem solving under two conditions: a "low task difficulty" scenario with only two goal variables to be controlled versus a "high task difficulty" scenario with four goal variables to be controlled. The system presented to subjects of the two experimental groups was, in fact, the same, but the task was different: In the "low complexity task" two out of four goal variables simply had not to be considered as goal variables.

The complete scenario consisted of eight variables, four exogenous, four endogenous variables. The employed system called ALTÖL (used oil) semantically refers to pollution by used oil including exogenous variables such as "control procedures" or "price of crude oil" and endogenous variables such as "maritime pollution" and "air pollution" (Funke, 1992b, S. 123).

Further experimental variation complemented the design: It was tested for effects of prior knowledge, effects of different degrees of controllability and effects of presentation

format, i. e. whether input and output information were displayed as either numbers (numerical type of presentation) or in charts (graphical type of presentation).[1]
With respect to dependent variables two types of measures appear relevant in this context, claiming a brief explanation: the concept of control performance and the quality of prediction.

Control performance provides a measure of how well problem solvers are able to reach and maintain the goal states they aim at. At least since the 1990s, achievements in control performance are usually computed as the mean deviations of the output values actually observed from their corresponding goal values.

Quality of prediction is a less frequently employed diagnostic tool which, in Dynamis research papers, has first been mentioned by Funke and Müller (1988). It is a measure of how well participants are able to predict future states of a CPS system, once the subjects know the current state and following interventions. Quality of prediction is computed in a similar manner as control performance: by the mean deviation of predicted values from the values that would – according to the system's underlying algorithm – actually have followed the current status if the intervention had taken place.

Exactly as expected, Funke's results showed a significantly lower control performance for the group dealing with the "high task difficulty" scenario. Obviously, it was easier to control only two rather than four variables. However, this finding was confined to problem solving under the condition of a numerical type of presentation. When input and output values were displayed graphically, the number of goal variables had no effect on control performance. The author only briefly points at a possible explanation: Perhaps only for numerical presentation, participants had the chance to analyse changes in states of input and output variables thoroughly enough so that different levels of control performance could occur.
Secondly and not expected, but in line with the first result, it was found that subjects predicted future system states significantly better when task difficulty was low (two goal variables) than when it was high (four goal variables). On the whole, the experiment supports the assumption that on several dimensions smaller systems, i. e. systems containing fewer variables, are easier to deal with than larger systems with more variables.

This general interpretation has yet given rise to more specific research. An experiment conducted by Preußler (1997) suggests that in addition to a system's mere number of variables, the variables' quality may be just as important or even more important. Preußler's experiment showed that under certain conditions subjects controlling a dynamic system in fact perform better if the system contains more variables.
60 students at the University of Bayreuth took part in the study. Their task was to control a Dynamis system named Linas (linear additive system). As in a typical CPS experimental paradigm relations and outcomes of interventions were unknown a priori. Since Linas variables have fancy names (e. g, Bulmin, Ordal, Trimol) no prior semantic knowledge can be expected to play a role in this task. Two different versions of Linas were presented to the subjects: Half of the students dealt with a simplified version which involved a set of four input variables and three output variables (control group). The other half (experimental group) learned to control a full version of Linas.

[1] These further experimental factors, however, will be discussed below in more detail.

Four additional variables were included, but – though participants were not informed about this fact – the extra variables were irrelevant to system control. Subjects in both conditions controlled LINAS for eight rounds with eight trials each. After that, they accomplished a decision task which was intended to measure the structural knowledge subjects had found out about LINAS. Pairs of variable names were presented, and participants had to decide whether there had been a relation between these two variables or not.
The major results concentrate on both control performance and the amount of knowledge acquired under the two conditions: Control performance, at least at the end of round eight, was significantly better in the experimental group as compared to the control group. Yet with respect to the acquisition of knowledge, the pattern was reversed, i. e. subjects controlling the simplified version outperformed those controlling the extended system; they had found out more about the relations within LINAS.
What might explain these findings? To Preußler, the results are exactly as predicted. Larger systems with irrelevant additional variables provide redundant information which requires cognitive capacity and hence means extra effort to subjects. That is why, according to Preußler, the experimental group did not show any superior performance in the initial rounds. At the end of the task, however, the benefits of redundancy outweigh its advantages. The larger system provides a "multiple learning context", learning conditions which could have allowed participants to try different approaches to the same problem. Just as with transfer tasks in traditional learning psychology, multiple contexts facilitate the control of the dynamic system. Preußler concludes that "learning contexts requiring additional cognitive resources for problem solving can have differential effects on the acquisition of structural knowledge and the acquisition of control knowledge" (p. 48). Thus, cognitive load due to redundant information obviously can enhance control performance and at the same time impair the acquisition of structural knowledge.

Another complementing contribution as to the impact of the number of variables in DYNAMIS has been proposed by Strauß (1993) in experimental studies and theoretical reflections. Strauß argues that in problem solving scenarios the number of variables per se is less decisive as to controlling and gaining knowledge than the question of how easily performance goals could be accomplished even if subjects were acting totally at random. In formal terms: Compared to all possible solutions, which is the amount of interventions leading to a certain goal state within a defined period of time? Strauß has termed this ratio the "share of correct solutions" (Strauß, 1993, p. 60). Using vector algebra the share of correct solutions can either be computed exactly from the full set of possible solutions or it can be estimated from samples.
In experimental studies Strauß has shown that performance in CPS scenarios can indeed be affected by this formal system characteristic. He compared subjects dealing with problem solving systems that were identical but for the share of correct solutions. In line with Strauß's assumptions, higher shares of correct solutions were associated with higher control performance whereas lower shares resulted in lower performance.
A second experiment revealed that even if two treatment conditions differed in the number of variables included, the share of correct solutions kept constant, regarding control performance no marked differences between the groups were found. Accordingly, for successful controlling of a dynamic system the system's size hardly matters as long

as it is easy enough to reach defined goal states when merely guessing.
Strauß pleads for the share of correct solutions to be treated as a system's formal feature which supplements the number of variables. Neither the number of variables nor the share of correct solution considered on its own is convincing; instead, both concepts seem confounded with one another. For full report, it should yet be mentioned that Strauß's findings proved to be valid for control performance, but that to CPS processes there are more determining factors than just this. With respect to the amount of knowledge acquired the share of correct solutions had no such effects in Strauß's experiments.

3.1.2 The number of relations

A second factor which determines the formal complexity of a system is the number of relations between variables. Even large systems with many variables may appear rather simple if there are only few interconnections between these variables. On the other hand, comparatively small systems can be constructed, involving, say, as few as six variables and yet being most intricate to solve since almost all variables affect one another in an unknown way. In research literature, this concept has been named the connectivity (" Vernetztheit") of a complex system.

Effects of connectivity as an experimental treatment factor have been investigated as early as 1985 by Funke (1985). The study involved a Dynamis CPS system named Ökosystem (ecosystem) whose cover story refers to gardening in an ecological context (the variables being labelled as "poison", "varmints", "fertiliser", "beetles", "water pollution", "number of leaves"). In Ökosystem there are three exogenous and three endogenous variables, i. e. a total number of six variables. For experimental study, the number of relations was manipulated to provide three different conditions: four relations in the condition of low connectivity, six relations for medium connectivity, eight relations for high connectivity. A further experimental condition concerning the presentation format resulted in a design with six groups, ten subjects per group. Participants task was to control goal parameters in a fictive ecosystem for five rounds with seven trials each.
In addition to control performance Funke measured the amount of knowledge subjects gained while exploring Ökosystem. Unlike in Preußler's study employing the "pair-task", Funke used the method of causal diagrams. In this paradigm, problem solvers are asked to formally express their findings about causal relationships with the help of arrows and symbols in diagrams. They draw arrows from one rectangle displaying a variable's name to another once they know that any relation exists between these variables (knowledge of relation). If they have found out that increments in one variable increase the outcome of another variable or that by increments in one variable another variable will decrease they add a plus or minus sign, respectively (knowledge of direction). In case they even know the exact numerical factor underlying a relation they put down a number (knowledge of strength). Hence, knowledge can be analysed on three increasing levels of accuracy. For each type of knowledge the quality of system identification is calculated from a formula involving the number of correctly identified items relative to the maximum detectable number of items and the number of mistakes.
The experiment supports the author's expectation that higher connectivity yields both

lower control performance and less causal knowledge than low connectivity conditions. Significant differences between the connectivity conditions were found for all three graduations of knowledge with knowledge of relation being most extensive, knowledge of direction having an intermediate state and knowledge of strength being relatively sparse in all three experimental groups.[2] More recently, Kluge (2003) reported comparable effects as to the impact of connectivity on CPS.

The interpretation that connectivity in a problem solving scenario can serve as a measure of task complexity appears to be obvious. It was Strauß (1993) again who pointed at a further explanation. Re-analysing Funke's experiment Strauß demonstrated that connectivity, the number of relations in ÖKOSYSTEM, has been confounded with the share of correct solutions as defined above: the less relations, the larger the share of correct solutions, the more relations, the smaller the share of correct solutions. As Strauß illustrates, controlling a system with only four relations between variables would be more successful than controlling an eight-relations-system even for random interactions with the system. These limitations may be taken into account even though one does not wish to fully abandon the first straightforward interpretation.

3.1.3 The quality of relations

The concept of connectivity can be specified further according to the types of relations between variables. For example, it may occur that input variables affect more than but one output variable each. In turn, output or endogenous variables can depend on a set of several input or exogenous variables. There may be parallel effects. Just as well it is possible that endogenous variables show influence on other endogenous variables, indirect effects which have been referred to as side effects. A third possibility concerning the quality of relations is the effect of an endogenous variable on itself. Challenged by problems in real life where systems' states often change without active interventions, without noticeable influences from known outside causes, in complex problem research, too, eigendynamics have become an established concept and experimental paradigm. A formal definition of eigendynamic (" Eigendynamik") is provided by Funke: "Eigendynamik means that an endogenous variable at time t has an effect on its own state at time $t + 1$ independent of exogenous influences which might add to the effect" (Funke, 1993, p. 322).

Parallel effects. Parallel effects have been studied with regard to two questions: Given the fact that in a dynamic system one input variable affects more than one output variable, what is the impact of different numerical weights shaping the relations between input and output variables? Will the strongest relation, i. e. the relation formed by the largest numerical weight, be detected and controlled more easily than other relations? Secondly one may ask under which conditions a system will be identified and controlled more successfully – if there is one input variable with parallel effects on several output

[2]The finding reported here applies to experimental conditions in which interactions with the system had immediate effects on the outcome states of the next trials (immediate feedback). In systems with so-called delayed feedback effects of connectivity on knowledge and performance were not quite as distinct. The influence of feedback delays will be described in a separate section at the end of part one.

variables or if there are several input variables that add to the outcome state of a single output variable.

The impact of parallel effects of different strength has been studied by Funke (1992b). As part of a larger series of studies examining side effects and eigendynamics, on the base of causal diagrams drawn by forty-eight subjects Funke analysed how well participants detected relations in a dynamic system called Sinus. The two relevant relations to be compared were an input-output-relation with a large numerical factor of 3 (dominant effect) and an input-output-relation with a much smaller numerical factor of only 0.5 (subdominant effect). The input variable was the same to both relations, the two output variables were different.
Frequency analyses were conducted in order to know in which category most of cases would be found: subjects who noticed the dominant effect at first and then the subdominant effect, subjects who noticed the subdominant effect earlier than the dominant effect, subjects who noticed both effects at the same time or subjects who noticed neither the dominant nor the subdominant relation. Since the majority of participants identified the dominant relation earlier than the subdominant relation, it is obviously easier to detect relations with larger impact on other variables although we do not know to what extent identification of a system is facilitated by increasing dominance. Neither there have been findings relating dominance or subdominance to successful or less successful control performance so far.

Another experiment described in the same publication (Funke, 1992b) dealt with the second question risen above, the impact different patterns of parallel effects have on solving a complex problem. In this context a formal concept from cybernetics (Ashby, 1958) has been introduced into the domain of CPS: the degree of controllability. Controllability in technical terms means the ratio of two numbers of variable classes: the number of variables that influence or control other variables divided by the number of variables that are influenced or controlled. In Dynamis scenarios a system's controllability is thus determined by the numbers of exogenous and endogenous variables. The more exogenous variables as compared to endogenous variables, the more easily the system should be controlled. Funke's idea was to figure out whether this theoretical and rather technical notion fits with control performance shown by human problem solvers. The design of the study has already been described in a previous section when dealing with system complexity due to the number of variables. Besides the number of variables and two further experimental variations concerning the Dynamis scenario Altöl Funke's experiment comprised three different degrees of controllability as a within subject factor. Within the whole of eight variables three independent subsystems could be separated: One exogenous variable affecting two endogenous variables (1:2 relation or low controllability), one exogenous variable affecting one endogenous variable (1:1 relation or medium controllability) and two exogenous variables affecting one endogenous variable (2:1 relation or high controllability). For statistical analysis data of 40 students were available.
The results showed effects contrary to the expectations. In fact, significant differences as to control performance for the three subsets occurred, but performance was best when the ratio of exogenous and endogenous variables was 1:2, i. e. for the subsystem which had been named the low controllability condition. In turn, it was lowest for the reverse

relation, which should have facilitated control performance according to the author's hypothesis. Medium effects were found for the 1:1 relation. In this condition high performance resulted if the variables' states had been presented in numbers whereas for graphical display performance was just as low as in the so-called high controllability condition.
Reflecting on these findings Funke has proposed methodological problems as alternative explanations, i. e. lacking independence of the subsystems from semantic features. So it remains unclear whether the psychological notion of controllability corresponds to the technical concept or not.

Side effects. Side effects in the context of CPS, too, have been studied by Funke (1992a, 1992b, 1993). For the study on side effects a Dynamis system named Sinus was chosen. Sinus comprises a total number of six variables, three endogenous variables, three exogenous variables, these being linked by four basic relations. In a standard version, two additional relations are implemented, one an instance of eigendynamics, the other a side effect of one endogenous variable on another. When dealing with Sinus participants are asked to control population numbers of six different tribes on a fictive planet in a solar system different from ours. The tribes are named "Gaseln", "Schmorken" and "Sisen", the endogenous variables or population numbers that have to be controlled, and "Olschen", "Mukern", "Raskeln", the exogenous variables or population numbers that can be manipulated by direct interventions. Relations between the six tribes on the fictive planet have to be explored and controlled for five rounds consisting of seven trials or simulated weeks. According to the standard procedure as employed in Funke's experiment rounds one to four are intended to serve knowledge acquisition due to the exploration of Sinus. Specific goal values to be aimed at are only given as late as round five when the main task demand is applying knowledge gained in earlier rounds.
In order to examine the impact of side effects on knowledge and performance Funke modified the system structure so that three increasing degrees of side effects were realised: One experimental condition without any side effect at all, a second condition implementing one small side effect with a numerical magnitude of 0.2 and a third condition implementing two side effects of 0.2 and 0.5.
Statistical analysis was based on scores of control performance and causal diagrams from 24 students, eight subjects per group. It was found that increasing side effects led to a linear decrease in the amount and quality of knowledge just as assumed prior to testing. The same effect occurred as to control performance which also decreased for systems with growing numbers of side effects. This fact has been interpreted as a logical consequence of limited knowledge acquisition associated with the side effects. Interestingly, as more detailed analysis revealed, in identifying the system's formal structure, subjects tended to compensate for mistakes in a rather systematic way: In case side effects had not been detected participants typically assumed additional relations between variables which, in fact, had not been manipulated at all.

Eigendynamics. Concerning the effects of eigendynamics an experiment analogous to the study on side effects was conducted (Funke 1992a, Funke 1992b, Funke 1993). Again 24 students worked on the dynamic system Sinus, following the procedure described

above. This time different degrees of eigendynamics were implemented in Sinus (while the number of side effects was kept constant): One version without any eigendynamics was provided, another version including one instance of eigendynamic with a magnitude of 0.9 and a third version including two instances of eigendynamic, the magnitudes being 0.9 and 1.1.
The magnitude of eigendynamics represents a numerical factor by which a variable's outcome value is multiplied from trial to trial. In case no eigendynamic contributes to the outcome state, this factor is set to the value of 1 (which is the default value in Dynamis). Accordingly, eigendynamics defined by the factor 0.9 lead to a ten percent decrease of the former state in each following trial. Speaking in terms of the Sinus cover story: Sisen, the Sinus tribe associated with eigendynamics of 0.9, will lose ten percent of its population each week and gradually die out unless appropriate interactions are undertaken. The reverse effect on Gasen, the Sinus tribe associated with eigendynamics of 1.1 will lead to a ten percent increase in population number if no counteracting measures take place.
Just like for growing degrees of side effects the author assumed that increasing levels of eigendynamic, too, would deteriorate both the quality of control performance and the quality of system identification, i. e. the amount and type of knowledge. The expectation was confirmed as to the quality of control performance since the three groups significantly differed in the predicted manner. The condition containing two instances of eigendynamic turned out to be especially hard to control. There was, however, no corresponding effect on the quality of identification. According to Funke, "causal dependencies were detected equally well under all three conditions" (Funke, 1993, p. 323).[3] He concludes that acquisition of knowledge and its application in the control task are different tasks requiring different abilities. Dissociations may therefore appear.

Perhaps still more interesting than considering side effects and eigendynamics each on their own it is to compare and combine the findings. The above results suggest that both side effects and eigendynamics, adding complexity to a problem solving task, make scenarios such as Sinus more difficult to handle. While successful identification of the system's structure obviously remains unaffected by increasing levels of eigendynamics, side effects impair the gaining of knowledge as well.
In order to corroborate the idea that in CPS systems side effects are harder to detect than eigendynamics, Funke applied combined frequency analyses on comparable data from three experiments of equal structure (the two experiments described above plus a third analogous study). Causal diagrams were selected from 48 participants who had worked on a Sinus version including one instance of eigendynamics and one side effect. The subjects were classified according to four exclusive categories: subjects who detected eigendynamics prior to the side effect, subjects who detected the side effect prior to eigendynamics, subjects who detected both eigendynamics and the side effect in the same round and subjects who detected neither of these relations. The first category was considered as in line with the expectations, the second category directly opposed it, the

[3]In an earlier publication Funke (1992b) notes that older measures of control performance and knowledge yielded effects for quality of identification as well. Obviously, however, the more recent measures should be preferred.

other two categories were deemed neutral or irrelevant to the expectations.
From a statistically significant ratio of 20 cases supporting the hypothesis and only ten cases opposing it, it was concluded that in Sinus eigendynamics indeed were easier to identify than side effects. A closer look at typical faults in the identification of the system revealed that often side effects which had remained unnoticed had been mistaken for additional eigendynamics leading to about the same outcome values.

Why could eigendynamics in Sinus be detected with relatively little effort? As Funke (1993, p. 323) points out, there is a rather simple strategy to notice eigendynamics in a CPS scenario: leaving the system to itself without any active interventions for one or more trials. This strategy can be applied in a very appropriate manner especially during the first four rounds of the experiment, i. e. when no specific goal values are provided. Under these conditions free exploration is both possible and desired. Unfortunate outcomes of interventions or omitted interventions do not matter as long as relations within the system are well identified. Certainly, in real life problems many people would rather refrain from strategies named "just wait and see". That is why from our studies we cannot necessarily conclude that eigendynamics are less relevant to problem solving than, e. g, side effects or parallel effects.

Feedback delays. Another feature finally appears to be typical of complex problems in the outside world beyond science laboratories. In reality, interventions rarely yield effects that can be noticed immediately after an operation has been carried out. Some effects may occur at once, others only occur after some time if at all.
In Dynamis effects in the long term have been modelled by means of feedback delays. In the Dynamis systems presented so far changes in a variable at a defined time t had an impact on outcome states of the trial following immediately, i. e. time $t+1$. This case shall be termed immediate feedback. Yet changes at t do not necessarily have to affect outcomes in $t+1$; instead they can "skip" one trial and affect, say, outcomes in t+2 or in times even further in the future. In this case the system's reaction to an intervention is deferred.
The already mentioned study by Funke (1985) employing Ökosystem was conducted to examine the role of feedback delays in CPS besides the impact of connectivity (see above). Including three different levels of complexity due to connectivity two different types of systems were constructed, one which contained immediate feedback exclusively and another in which part of immediate feedback relations were replaced by corresponding relations with delayed feedback. Half of the 60 participants were assigned to work on each system.
It was expected that feedback delays should be more difficult to identify and to control than immediate feedback. Indeed, the results showed more and better knowledge gained by participants who had been given immediate feedback instead of delayed feedback. Significant effects appeared for three distinct types of knowledge: knowledge of relation, knowledge of direction, and knowledge of strength. With regard to interactions between feedback delay and the second experimental manipulation, the complexity due to connectivity, the feedback manipulation seemed to give rise to differential effects of connectivity. While for subjects solely confronted with immediate feedback increasing connectivity consistently resulted in decreasing accuracy of knowledge, in the condition

of delayed feedback it was only the medium connectivity group who identified less relations than the low connectivity group; participants in the condition of high connectivity identified the system almost as well as the low connectivity group. Funke has attributed this unexpected finding to enhanced effort and extra time spent on the task by subjects dealing with both delayed feedback and high connectivity. Effects of feedback delays on control performance, unfortunately, turned out to be unsuitable to statistical testing. Since in recent Dynamis studies feedback delays have hardly been examined we can only guess that the immediate feedback should rather facilitate control performance than systems including feedback delays.

3.2 Task characteristics

Occasionally recurring to the basics of part one, in the following sections we will consider broader applications of CPS scenarios. Leaving the mere formal attributes of Dynamis systems we will shift the focus to the interaction between the person, i. e. the problem solver, and the system.
How should information be presented in order to facilitate working on a complex system? What are relevant and appropriate task demands providing an insight into the process of CPS, and how are differential demands – such as the acquisition and application of knowledge – interrelated? Finally, which methods can be employed in terms of training or task instructions to support successful interactions with the system? These may be the leading questions to the section about task characteristics.

3.2.1 Format of presentation

The first question risen above was: How should information be presented in order to facilitate working on a complex system? Although it seems nearly impossible to find a definite answer applying to all instances of CPS we will have a closer look at the impact two prominent task characteristics have on different facets and demands in problem solving: Numerical vs. graphical format of presentation and semantic embedding.

Numerical versus graphical format of presentation. In the sections on system characteristics it has been briefly pointed at the fact that in Dynamis scenarios information as to the state of input and output variables can be displayed either in numbers or in diagrams, which implies two different modes of the user's interface. All of the studies discussed above – unless it has been noted explicitly – dealt with systems of the numerical format. According to Beckmann (1994, p. 65) this mode of presentation is far more common than graphical interfaces. Recent scenarios of the numerical mode show variables' states as numerical values in tables. For interventions numbers have to be entered by using the keybord.
In his own studies Beckmann employed two Dynamis systems of the graphical type, Kirschbaum (cherry tree) an Maschine (machine).[4] In these scenarios exogenous variables can be manipulated by means of three different mouse buttons on a control

[4]In fact, the systems are identical in their formal structure, but different in semantic embedding. This will be considered more closely in the following section.

panel: one button for zero interventions, another button for increasing the value of a chosen exogenous variable, the third button for decreasing the value of a chosen exogenous variable. The relative size of the values can be inferred from the length of a vertical bar: the longer the bar, the higher the corresponding numerical value. Positive or negative values are symbolised by the bars position above or below a “zero intervention line”, respectively. Line diagrams, on the other hand, present the course of previous states and actual states relative to top and bottom limitations and relative to goal values marked by a straight horizontal line.
Another descriptive example of graphical features in Dynamis is given by the dynamic system MultiFlux (Kröner, 2001). MultiFlux has been developed as the simulation of a fictive machine. The machine consists of four regulators or control devices, i. e. the exogenous variables, and four instruments depending on the regulators, i. e. the endogenous variables. Variables are labelled control devices 1 to 4 and instruments 1 to 4. To problem solvers the task is to adjust regulators so that the instruments will reach defined goal adjustments. In doing so, they are confronted with a graphical display optically similar to the control buttons in real technical instruments such as hi-fi systems.

While in Beckmann’s and Kröner’s studies it has not been the primary aim to examine impacts of graphical presentation on CPS, Funke (1992a, 1992b) conducted experimental comparisons of the two different modes of presentation. In studies based on the data of 80 students he analysed problem solving in a graphical vs. a numerical version of the already mentioned eight variable system Altöl. Almost as in Beckmann’s Kirschbaum and Maschine the graphical interface displayed the course of outcome values in line diagrams. An additional horizontal line indicated the level of the corresponding goal value. Type of presentation was one experimental factor among others such as task difficulty, degree of controllability and a manipulation referring to the role of prior knowledge.
Former studies dealing with scenarios other than Dynamis systems had suggested that control performance would be facilitated if information were displayed in diagrams as compared to numerical tables (see Hübner, 1987, 1988). Opposing that view, Funke (1992a) hypothesised that subjects dealing with numerical interfaces would outperform the graphical presentation group in control performance, but that the identification of the system would be better if graphical information were provided. Yet neither of the these expectations could be supported (nor could be the opposite). Only when additional factors such as task difficulty were taken into account significant effects of interaction appeared: Provided that participants controlled a system with only two goal variables (low task difficulty) better identification of the system’s relations was found for the numerical than for the graphical condition. In turn, if four goal variables had to be controlled (high task difficulty), participants in the graphical condition identified the system’s structure more easily. Funke concludes that “presentation format per se is not a critical factor. However, it is obvious that depending on the nature of the task, differential effects occur: In order to cope with the more complex task the graphical presentation which is less precise in presenting system information yields better results (Funke, 1992a, p. 37)”.

The same notion is supported in another analysis by Funke (1992b). In this paper the author reports a study which revealed no significant differences as to the quality of system control and the quality of system identification. Interestingly, the format of presentation seemed to affect some motivational factors which had been recorded by means of questionnaires for the purpose of experimental control. At the beginning of the task subjects confronted with the numerical presentation reported higher "failure motivation", i. e. higher anxiety to fail on the task, and lower readiness to make an effort. Fortunately, however, at least in this context, impaired motivation had no striking detrimental effects on the overall performance and identification. Only for a third diagnostic measure, the quality of prediction, numerical presentation as compared to the graphical mode seemed to facilitate the task demands. However, since in both conditions subjects had to predict future outcomes in numbers (instead of graphical predictions) differential experience with the numerical mode might be regarded convincing enough to offer an alternative explanation.

Semantic embedding and the role of prior knowledge. Thinking of abilities and skills relevant to CPS, personality factors such as intelligence and a "feeling" for successful strategic approaches (compare Dörner's concept of operative intelligence, e. g, Dörner, 1986) probably come to our mind in the first place. Yet just as well we might think of practice and the knowledge a problem solver has gained prior to the task in contexts associated with the task demands. This, too, should affect a person's interaction with a given dynamic system.

With regard to the role of prior knowledge the Dynamis scenarios discussed in the above sections can be assigned to two classes. Scenarios such as Sinus (the fictive planet), Linas (fancy names) and Kröner's fictive machine MultiFlux have been constructed to be relatively neutral to prior knowledge. Although problem solvers may be familiar with the concept of a machine, when confronted with MultiFlux, they will not know whether and how control device number 1 is likely to affect instrument A, for instance. Systems of these properties will be referred to as systems without semantic embedding. In contrast, semantically embedded Dynamis scenarios like Altöl or Ökosystem refer to rather familiar contexts. Dealing with Ökosystem anyone with a basic idea of gardening and ecology can make up his or her own expectations once he or she has but realised the variables' names: "poison", "varmints", "fertiliser", "beetles", "water pollution", "number of leaves". Will poison lead to increasing water pollution? Will fertiliser, brought into play, induce growth and increase the number of leaves? Hypotheses such as these may be formed immediately unless there is no prior knowledge at all.

In order to elucidate effects of prior knowledge on CPS one common approach is to examine how "experts", i. e. problem solvers with sufficient relevant prior knowledge, cope with dynamic systems, as compared to "novices" without relevant prior knowledge (see, e. g, Reither, 1981). This, however, does not concern Dynamis systems in particular and will not be the subject of the present paper. A second approach which is more closely related to Dynamis is found by comparing problem solving in semantically embedded systems to problem solving in systems without semantic embedding. For valid comparisons, of course, systems have to be identical in structure and user's interface but for the different names of exogenous and endogenous variables.

This is exactly the essence of Beckmann's (1994) research on semantically embedded systems. For experimental studies Beckmann employed the semantically embedded system Kirschbaum (cherry tree) which contains three exogenous variables labelled "light", "water supply", "warmth" and three exogenous variables named "cherries", "leaves", "beetles", hence appealing to general knowledge. According to the cover story, participants explore and influence growth and growth conditions of a hardly known type of cherry tree. In Maschine, the equivalent version without semantic embedding, exogenous variables are represented as control devices, endogenous variables are represented as instrumental displays. Preliminary examinations based on a sample of pupils made Beckmann assume that semantic embedding as a system's property had an effect on an identification task, but seemingly not on control performance. In order to replicate the quasi-experimental findings he realised a first experiment which involved 40 participants, students at the University of Bonn. Half of the students explored the semantically embedded system Kirschbaum for two rounds with seven intervention trials and afterwards controlled the system for one round in order to accomplish defined goal values. The other half did the same task on Maschine.
As expected, subjects in the condition without semantic embedding identified the system's structure better than those dealing with the semantically embedded system. A likely interpretation to this finding is that the semantic context in Kirschbaum triggers participants' prior knowledge and their assumptions about relations, which, in fact, are incompatible with the relations specified in the Dynamis linear equations (hypothesis of knowledge incompatibility). However, more astonishing, though also expected from the preliminary analysis, control performance was about equal in the two groups; in spite of less knowledge gained the subjects in the semantically embedded condition did not control any worse.
If knowledge incompatibility is indeed a crucial determinant to differential achievements in problem solving, why should control performance remain unaffected? Beckmann argues that even with regard to knowledge acquisition "explicit knowledge incompatibility" offers an at least incomplete explanation (see p. 172). Relations between variables in the Kirschbaum scenario implied no serious incompatibilities to subject's prior knowledge. More noteworthy, a closer look at identification patterns revealed that the relations subjects detected well or not so well in the semantically embedded system coincided with the equivalent relations in the scenario free of semantics.
Instead of knowledge incompatibility, Beckmann pleads for two processes of knowledge acquisition which are different in quality, not but in the quantity of resulting gained knowledge. Concerning systems without semantic embedding a constructive process of knowledge acquisition is proposed. Since, due to lacking semantics, no prior knowledge is "activated" and no expectations are available, the default assumption about possible relations between any two variables is that there is no relation. Only after interactions with the system, an internal model about structural relations will be built up, successively extended and refined. The reverse process should be the case for people dealing with semantically embedded systems. According to Beckmann, semantic contexts as in Kirschbaum give rise to the default assumption that each variable depends on all other variables. The structural model of knowledge is formed and refined in a reductive process, gradually decomposing the model of general interconnection. As the reduc-

tive process takes more cognitive effort less knowledge should be gained in semantically embedded scenarios. Beckmann's data obviously fit well with the assumption of two different models of processes.
But what about control performance? What can explain the fact that control performance did not seem impaired in a semantically embedded system? Beckmann's idea is that there are at least two different ways of controlling dynamic systems, though probably not equally useful. The first process is control performance based on gained knowledge. This is, of course, assumed to be the primary process guiding participants who cope with MASCHINE and do well on both the identification task and the control task. But even for participants dealing with KIRSCHBAUM episodes of good identification preceded or coincided with episodes of good control performance. Only if control cannot – because of insufficient knowledge – be based on knowledge a second process named "ad hoc" control comes into play: basic rules or heuristics which do not apply to a certain dynamic system in particular ("situationally unspecific heuristics"). By means of "ad hoc" control subjects who controlled the semantically embedded version might have compensated for limited structural knowledge.
To validate this notion, Beckmann designed a second experiment involving control conditions which should only enable "ad hoc" control. Knowledge acquisition was said to be prevented by leaving out the former two exploration phases and replacing them by control phases with specific goal values to be accomplished. It was expected that as to control performance no marked effects of semantics should occur then. With regard to scenarios and general procedure, the second experiment equalled the first one. 51 school students from Leipzig area participated.
Not fully consistent with the expectations, in experiment two results indicated some influence of semantic embedding on control performance although not all effects turned out to be statistically significant. For both experimental conditions, performance increased in the course of the three rounds, yet for subjects in the KIRSCHBAUM condition the effect was more prominent: The pupils working on KIRSCHBAUM started with a lower performance in the first round as compared to the those working on MASCHINE, in the second round the performance of the two groups was equal and in the final third round subjects of the semantically embedded condition even tended to control better.
Beckmann hence answers the second question as follows: Although control performance with semantic contexts appears to be the same level as with contexts free of semantics performance is indeed impaired. Consequences of the deteriorating effect of semantic embedding, however, are only obvious and determinant at the beginning of the process of CPS. Early phases of exploration or additional rounds of control, fostering successful "ad hoc" control will make the effect vanish. As Beckmann illustrates impaired control performance due to semantics, "it is obviously easier to understand and control a system if 'you know that you know nothing' (MASCHINE) than if 'you think you know something' (KIRSCHBAUM)" (Beckmann, 1994, p. 199). Further research on semantic embedding and the role of intelligence in CPS is provided by Beckmann and Guthke (1995, see below).

Besides comparing experts vs. novices and experiments on semantic embedding there is a third approach to study impacts of prior knowledge on problem solving. While in the experimental designs described above systems with exactly equal structural relations, but a different "surface" have been employed, it is just as possible to compare two systems, both semantically embedded, with the same number and names of variables; these will look the same in superficial characteristics, but the underlying structure may be different. In research done by Funke (1992a, 1992b) two such systems, different versions of the ALTÖL scenario were constructed. They were even identical in the general structure but for the signs of parameters in linear equation models. One version, the matching condition, was assumed to coincide with participants' prior knowledge while the other version, the mismatching condition which contained inverted signs of parameters, disagreed with expected knowledge. It was statistically tested for effects of knowledge compatibility on the three measures quality of system control, quality of system identification and quality of prediction. Each of these variables turned out to be significantly impaired for the mismatching condition, the ALTÖL scenario containing counterintuitive relations. The results, reflecting straightforward expectations, once again confirm that prior knowledge definitely requires consideration in cognitive research, even though in most cases little is known about knowledge specific persons have about specific tasks (compare Funke, 1992b, p. 139).

3.2.2 Task demands

As the introduction and preceding chapters have underlined already, there are at least two essential demands to a person dealing with a complex dynamic system. Firstly, he or she has to find out how the system works, secondly, he or she is asked to reach and maintain a certain goal state of the system. If psychological research wishes to get a functional insight into processes of CPS, it needs to focus on both: on subjects' performance in identifying the system, i. e. his or her acquiring knowledge, as well as on subjects' control performance, often termed as knowledge application. In this section we will try to elucidate how acquisition and application of knowledge depend on each other. Prior to that, however, let us briefly recapitulate that in experimental practice several indicators exist to record the type and amount of gained knowledge and the quality of control performance.

Measuring acquisition of knowledge. Regarding acquisition of knowledge, the far most common experimental indicator is the structural score gained from the method of causal diagrams in the paper and pencil format (see, e. g, Funke, 1985). Computer-based modifications of this method exist in some rather exceptional cases. In studies, e. g, by Beckmann (1994) or Schulz (2003) the analogous format of arrows in diagrams is either complemented or replaced by verbal and numerical elements. Beckmann recorded participants' structural knowledge by means of sequential verbal questions after each experimental trial. Subjects were confronted with very general questions first (such as the question whether they had found out anything new about any relation in the dynamic system) and later – in case subjects had answered accordingly – more specific questions followed (such as the question concerning the strength of the relation between two defined variables). Hence, the level of specifity was adapted to participants' individual knowledge. Verbal answers of the question sequence then were translated into an analogous format, i. e. into arrows and symbols between exogenous and endogenous variables implemented in the system's graphical user's interface (see Beckmann, 1994, p.

72). In Schulz's diploma thesis (2003), the method of causal diagrams was completely transformed into a tabular display leaving room for the same information as can be specified in a graphical causal diagram.[5]

Although the method of causal diagrams has been criticised due to its potential reactivity, i. e. the fact that the way of recording knowledge draws subjects' attention to causal relations to an unnatural, exaggerated extent (see Kluwe, 1988, p. 370), there are two major advantages of this method. Firstly, causal diagrams allow differentiated analyses of three levels of system identification: the identification of the existence or non-existence of a relation, the identification of a relation's direction and the identification of a quantitative weight indicating the strength and direction of a relation. Secondly, measures developed on the base of causal diagrams have proved highly reliable, especially the indicator quality of knowledge acquisition, which has been validated by Müller (1993) in extensive studies. Quality of knowledge acquisition defines a weighted difference of ratios of correct and false answers relative to the maximum numbers of correct and false items (see also Funke, 1992b, p. 81 ff.). Another approach to measure structural knowledge is found with Preußler's "pair-task" (Preußler, 1996, 1997, 1998). In the "pair-task" pairs of two variables' names are presented to subjects who decide whether a relation between these variables exists or not. According to Preußler, the pair-task is considered less reactive than the method of causal diagrams, yet information about gained knowledge is confined to the mere knowledge of existent or non-existent relations.

While causal diagrams and the "pair-task" aim at recording abstract structural knowledge about causal relations in a system, in terms of acquired knowledge it is also possible to examine knowledge on a more concrete level, closer to the application of knowledge. Schoppek (2002), e. g, emphasises the distinction between structural knowledge and input-output knowledge which "represents specific input values together with the corresponding output values". Accordingly, in order to consider this type of specific knowledge as well, participants may be asked which will be the resulting outcome states provided certain input states and interventions. The measure calculated from such predictions and the actually resulting outcome states is named the quality of prediction (see Funke, 1992b, Funke & Müller, 1988). Another way to infer input-output knowledge is to present specific system's states which either correspond to dynamic situations actually occurred (target situations) or to additionally constructed distractor situations which resemble target situations but have never been encountered by subjects (Preußler, 2001). Subjects are requested to assess whether a presented situation is "old", i. e. a target, or whether it is completely "new" to them, i. e. a distractor. On the base of correct and false recognition answers knowledge scores can be calculated.

Even though the latter measures can possibly be regarded as less reactive than causal diagrams, problem solvers confronted with these demands still know that they are asked about explicit structural knowledge they have gained. It was Preußler (1996) who suggested and conducted an attempt of recording rather implicit knowledge. In Preußler's lexical decision task participants are interrupted in the actual task of CPS just as with causal diagrams or the "pair-task", but they do not know that the intermittent task

[5]The reason for this practice were not general objections against graphical causal diagrams, but a specific experimental manipulation which might have interfered with graphical display of the system's structure.

intends to gain an insight into their knowledge. Subjects in the experimental setting are simply asked to decide as quickly as they can whether a variable's name presented in a temporal sequence on the screen refers to a "real" variable or to a similar, non-existent variable's name. In diagnosing knowledge the decisive measure is provided by records of reaction time rather than by the mere distinction of correct or false reactions. As common in research on associative priming (compare Goshen-Gottstein & Moscovitch, 1995) it is assumed that problem solvers will react to a correct name more quickly if the preceding item represents the name of a variable which is – within the examined complex system – indeed related to the other variable. The approach seems both appealing for its comparable non-reactivity and prone to criticism: Certainly it is a daring business to infer associations from reaction times and structural knowledge from superficial associations (compare Funke, 2003, p.166).

Measuring control performance. Control performance on the other hand is measured almost consistently throughout recent experimental studies by means of the quality of system control. This measure calculates mean logarithm deviations of systems' observed states from defined goal states (see, e. g, Müller, 1993, p. 61). Shown by Müller's validating analyses, quality of system control as an experimental tool is just as reliable as the quality of system identification.
A measure found in older studies is given by mean absolute deviations from goal values (e. g, Funke & Müller, 1988). In the exceptional case of a special paper and pencil DYNAMIS adaptation (Görn, Vollmeyer & Rheinberg, 2001) merely counting the number of accomplished goals can be an indicator of control performance as well.

Knowledge acquisition: active exploration vs. passive observation. So far we have considered processes of knowledge acquisition as a result of subject's specific interventions and experiences with dynamic systems. Phases of system control and active exploration have been interwoven with the formation of structural knowledge. In reality, however, this is not necessarily the case: In some situations we better learn from pure observation. Maybe this is true for some aspects of CPS as well?

This question was risen and investigated in an study by Funke and Müller (1988; see also Funke 1992a, 1992b, 1993) based on the data of 32 college students. Using SINUS, the authors implemented a new experimental design which is suitable to comparing effects of active intervention vs. passive observation on problem solving. Active intervention was realised as in traditional experiments whereas participants in the condition of passive observation received the intervention data from an "experimental twin" of the intervention group (yoked control-design). During four initial exploration phases they but observed input states, the twin's intervention values and corresponding outcome states. Like the intervention group they filled out causal diagrams after each round. These blocks of either active or passive exploration were followed by one round requiring active control of the dynamic system from all participants.
Prior to statistical testing Funke and Müller expected a general superiority of the intervention group with regard to both the amount of knowledge and the quality of system control. Their assumption was only partly supported. As path-analytical expectation revealed, subjects who actively explored SINUS showed indeed better control performance

than the passive observers. The observers, however, had gained significantly more and better knowledge about the system, especially with regard to exact numerical parameters. An explanation proposed by the authors points at differential perception of the experimental demands: While subjects asked to actively explore and control the system may consider the final control task as their primary task demand, to their experimental twins in the observers' condition, knowledge acquisition and producing valid causal diagrams, being their only active contribution during the exploration blocks, should appear far more important.

Partially differing results and interpretations are found in Beckmann's (1994) research which is dedicated to learning in traditional learning tests as compared to CPS in the first place, but which additionally deals with effects of active vs. passive exploration on problem solving. Beckmann's terms active and passive exploration correspond to Funke's and Müllers concepts of active intervention vs. passive observation, respectively. Only unlike in the above experiment, passive exploration in Beckmann's practical realisation implies observing system's states which have been prepared by the experimenters in order to represent information resulting from possible optimal exploration strategies. The yoked-control design is replaced by displaying informative data identical to all observers. With regard to the scenario employed (MASCHINE, a six variable system free of semantic embedding), with regard to general procedure, and the number of participants (40 students) Beckmann's experiment seems comparable to Funke's and Müller's study.
The results, however, are different. Beckmann could not replicate the finding that subjects in the observers' condition gained significantly more structural knowledge than subjects who actively intervened. The observers even tended to identify less precise although this effect failed statistical significance. Concerning control performance, Beckmann's participants, too, performed better if they had actively explored the dynamic system. This finding has been interpreted in terms of different procedural skills that arise from different task demands. Beckmann assumes that when actively controlling a system former observers can only rely on the declarative knowledge they have acquired during observation while active explorers on the other hand gain and make use of both declarative and procedural, often implicit knowledge about the system's reactions.
For the subsequent sections on knowledge acquisition and knowledge application we can at least keep in mind that knowledge can be gained both from participants' active intervention as well as from passive observation. As we will see with studies providing additional structural knowledge to subjects besides the knowledge from active exploration both active and passive ways of knowledge acquisition can be combined.

A closer look at the relation between knowledge acquisition and control performance. It is commonly assumed that acquiring knowledge represents a necessary precondition for controlling a dynamic system. As in the above text, too, most scientists interpret system control in terms of applying gained knowledge.[6] That is why in

[6]Interestingly, the reverse path, i. e. whether and how control performance in turn affects knowledge acquisition has been examined far less frequently. Assumptions as to the question whether successful control performance encourages increased knowledge acquisition appear to be controversial. Preußler's (2001) research on the base of a DYNAMIS scenario suggests that at least gaining specific input-output

experimental practice, phases of free exploration, aiming at knowledge acquisition, usually precede phases of controlling a dynamic system with respect to defined goal values, aiming at knowledge acquisition.
Although in general there is empirical evidence for this theoretical notion, we will see that findings on the relation between knowledge acquisition and control performance are not quite as distinct for several reasons: Knowledge relevant to control demands can be explicit and abstract or rather implicit and concrete to differing degrees; furthermore, mediating factors exist that make it more or less probable that problem solvers in control tasks actually make use of acquired knowledge.

Correlation analyses. A straightforward approach to investigate the relation between knowledge acquisition and control performance is to analyse statistical (a posteriori) correlations between these two indicators in CPS. Funke and Müller (1988) already found positive statistical correlations ($r = 0.41$ or – for revised diagnostic measures in Funke, 1992b – $r = 0.54$) hence indicating that the degree of knowledge acquisition will determine the level of control performance. The possibly most prominent demonstration of this relation is found with Müller's (1993) analyses based on the theory of latent state-trait models (e. g Steyer, Schmitt, & Eid, 1999). LISREL analyses, the practical implementations of this model, enable separating manifest variables, i. e. variables that are empirically observed, from latent variables, i. e. variables assumed to form an underlying, non-observable psychological construct. With respect to CPS it was Müller's idea to distinguish manifest knowledge and control performance in specific DYNAMIS situations from corresponding latent traits of system identification and system control as problem solvers would reveal irrespective of situational influences.
For empirical validation 143 school students worked on SAB, the DYNAMIS computer simulation of an abstract machine (a precursor of Kröner's MULTIFLUX system). For LISREL requirements two sessions with two equivalent SAB versions were conducted, unfortunately reducing the number of complete data to 78 participants. On the base of the LISREL procedure Müller showed that for the latent variables corresponding to manifest system identification and system control correlations were significantly positive ($r = 0.83$ for the first session, $r = 0.86$ for the second session; for a brief summary of Müller's procedure and results see also Funke, 2003, p. 163-165). Müller's analysis furthermore suggests that the trait of system identification can be regarded as a one-dimensional construct, dismissing any implicit or procedural knowledge specific to control performance. According to Müller, control performance can fully be predicted on the base of subjects' abstract knowledge about causal relations in the system (p.208).
Another interesting aspect of Müller's work provides one possible explanation as to empirical findings inconsistent with Müller's positive correlations between identification and control of a complex system. In a small experimental sample of 20 students Müller showed that the amount of knowledge gained obviously depends on some facet of presenting information about the system's state. Students who were – during a problem solving task – confronted with a simultaneous presentation of actual and past system's

knowledge is not systematically related to control achievements. Yet in this section the discussion of relevant DYNAMIS studies will focus on the more obvious relation: how control performance depends on acquired knowledge.

states gained more and better knowledge than those who viewed but one system's state at a time, the actual system's state which was replaced by the subsequent state in the following trial (sequential presentation). Given simultaneous presentation participants seemed to benefit from extra time spent on the task whereas in the condition of sequential presentation this was not observed. The author concludes that simultaneous display provides the possibility of analysing the course of the system's development, a necessary condition for acquiring knowledge. In turn, since only with simultaneous display subjects acquired sufficient knowledge, only in this condition positive correlations between system identification and system control may occur whereas for sequential presentation correlations are – or rather seem – insignificant.
The notion that acquired structural knowledge can predict goal attainment is also supported within more comprising path-analytical models by Vollmeyer and Rheinberg (1998), Beckmann and Guthke (1995) as well as Kröner (2001). Correlation coefficients range from 0.51 with Beckmann and Guthke to 0.65 in Kröner's experiment or 0.59 when it was statistically controlled for the impact of test intelligence. Similarly, Vollmeyer, Burns, and Holyoak (1996) found that for both an initial control task as well as for a transfer control task structural knowledge measured by a structural score revealed significantly negative correlation coefficients when correlated with the solution error, the absolute difference between a target value and the observed value ($r = -0.57$ for the initial control task, $r = -0.65$ for a transfer control task). All of the correlations reached significance or even high significance making a general dissociation between system identification and system control appear highly improbable.

Yet it should be mentioned that the obvious relation between gaining and applying knowledge may be mediated by various influences. One such influence has already been discussed with Beckmann's (1994) study on the impact of semantic embedding in complex dynamic systems. Positive correlations between achievement on the two task demands rather occurred when the system was abstract than semantically embedded. In Kluge's (2003) work task difficulty has proved to be another mediating factor. In a large-scale experiment involving 496 subjects working on the Dynamis system ColorSim (see below), among other factors formal task complexity was manipulated by three levels of increasing connectivity. Correlation coefficients as to acquired knowledge and control performance were found to be high for a low or medium degree of connectivity ($r = 0.70$ and $r = 0.68$, respectively), but it was considerably lower for subjects who had dealt with the most complex version ($r = 0.44$). Possibly in the latter case additional factors, e. g, the amount of time spent on the task became more influential, hence lowering the statistical correlation.

Manipulating structural knowledge: the impact of transparency. The a posteriori correlations described in the preceding section obviously provide an appropriate tool to detect that there is, in fact, a positive relation between the two task demands in CPS and that this relation is relatively powerful. Yet the results remain confined to a descriptive level because no causal relation is implied by correlation analyses. In order to find out more about the mechanisms which determine how knowledge is translated into control performance experimental manipulations in this context are necessary. If the researcher is interested in the effects of structural knowledge on control performance, he or she can try to systematically promote or impair subjects' structural knowledge and observe whether and how control performance will be affected. The first methodological approach has been realised in a number of experimental studies. Since structural knowledge is fostered by providing diagrams which present the system's structure, making the system "transparent" to a problem solver, the term transparency will be applied to systems whose structure is disclosed to subjects.

In a sample of 50 university students Putz-Osterloh (1993a, 1993b) conducted an experiment on possible effects of transparency on problem solving in order to examine the relation between knowledge acquisition and system control. Participants dealt with a version of LINAS which involves four input variables (named A, B, C, D), seven output variables (having fancy names) and 15 relations, some of these characterised by delayed effects. In a first part of the experiment subjects' exploring and controlling the system was required. The task was identical for all subjects but for a manipulation on structural knowledge: Subjects of the experimental group (25 students) were given a structural diagram displaying the relations within LINAS; the diagram was explained by the experimenter, and by standardised questions it was ensured that subjects had understood relevant information. Subjects of the control group (25 students) received no structural information.

Putz-Osterloh assumed that students of the experimental group would benefit from the extra knowledge due to transparency and would perform more successfully in controlling LINAS. Yet the expectation could not be confirmed. As to control performance no systematic differences between the two transparency conditions were found although subjects of the experimental group indeed seemed to have more structural knowledge than those of the control group.[7] A first conclusion therefore contradicts the above suggested coincidence of knowledge acquisition and control performance. On the base of the experiment's first part one might rather suppose that these are two independent processes in CPS. According to Putz-Osterloh and similar to Beckmann's (1994) notion of ad hoc control, it might be possible to successfully control a system despite little knowledge, acting almost in terms of trial and error.

When, however, can structural knowledge still support performance in a complex dynamic system? A second part of the experiment suggests that structural knowledge provided by diagrams can, although not applicable immediately after its acquisition, enhance control performance in a transfer task. Half a year after the first session, 38 students of both the experimental and control group from Putz-Osterloh's original sample worked on a modified or "flawed" version of LINAS in which the effect of one input variable had been omitted. Participants were informed about this fact, yet they did not know which variable had been changed. They were requested to name the deficient variable after controlling the dynamic system.

As expected, this time subjects formerly supported by structural knowledge outperformed subjects of the initial control group, again applying more efficient strategies. They also proved to be more successful in diagnosing the modification. Interestingly, for participants of the former experimental group a positive correlation was found concerning the amount of reproduced structural knowledge (as could be inferred from the

[7] Especially the finding that participants supported by transparency adopted more efficient strategies made the author assume that these subjects indeed made use of their enhanced structural knowledge.

diagnosis task) and control performance. Subjects of the former control group whose knowledge acquisition had not been systematically promoted on the other hand revealed no such systematic correlation. Instead, Putz-Osterloh states a dissociation: Problem solvers who easily detected the system's modification tended to do relatively badly on the control task, not adopting their strategies to the modified system's structure, whereas other subjects seemed to cope successfully with the changed version although they did not detect which variable had been manipulated.

Possibly, Putz-Osterloh argues, in the initial task subjects confronted with abstract knowledge indeed acquired helpful, comprising structural knowledge, but the demands of analysing and interpreting the graphical structural diagram occupied their cognitive capacities almost completely so that they could not apply their comprising knowledge right from the beginning. Supporting effects of structural knowledge on control performance only became obvious in the transfer task after the process of knowledge acquisition had been completed. With respect to the relation of acquiring structural knowledge and accomplishing the control task Putz-Osterloh, partly disagreeing, e. g., with Müller's (1993) interpretation, assumes that both demands can still be conceived as two separate goals. As shown by the dissociation found in Putz-Osterloh's control group the goals are not necessarily coordinated, but they well may be if problem solvers' structural knowledge reaches a sufficient extent.

Preußler (1996) as well examined the role of structural knowledge and control performance in Dynamis situations and adapted the view that there might not necessarily be a direct translation of structural knowledge into applied knowledge in control performance. Two successive experiments emphasise that in actually applying gained knowledge at least two conditions need to be accomplished: Firstly, structural knowledge has to be gained in the context of application instead of abstract "inert" knowledge, secondly, knowledge acquisition should take place prior to application.

With respect to structural knowledge, Preußler did not but analyse explicit verbalised knowledge recorded by the "pair-task", but also implicit associative knowledge about structural relations which was inferred from a lexical decision task. Both qualities of knowledge were to be considered to examine whether implicit rather than explicit knowledge was associated with successful control performance as Berry and Broadbent (1984) had suggested.

Similar to Putz-Osterloh, yet closer to knowledge application, structural knowledge in the transparency condition was promoted by specific examples and explanations. Within a total sample of 50 students (studying at the University of Bayreuth) half of the students, the experimental group, passed through a practice phase before the control task: The experimenter told them – according to standardised examples – how to manipulate certain input variables and explained subsequent effects on output variables to them. The remaining subjects forming the control group explored the dynamic system without requests and explanations before they worked on the same system for eight rounds with eight trials each. The Dynamis system chosen for this task was a version of Linas.

Three experimental hypotheses were to be tested for statistically. Firstly, the experimental group systematically supported in gaining structural knowledge should reveal more knowledge as to both the explicit and implicit measure. Secondly, as a consequence of

enhanced knowledge acquisition the experimental group should outperform the control group in controlling Linas. Thirdly, the amount of gained knowledge, both implicit and explicit, should be a predictor of control performance. The first experiment, however, supported neither of these assumptions. Only marginal support was found with regard to enhanced implicit knowledge in the experimental group (first hypothesis) and a positive relation between knowledge and system control (third hypothesis).
It was the second experiment involving another 48 university students for participation which confirmed that subjects systematically promoted in knowledge acquisition displayed indeed higher levels of implicit knowledge as compared to those of the control group. Control performance, too, tended to be higher within the experimental group. What had been changed in the second experiment relative to the first experiment? According to Preußler, the procedure of instructing knowledge had been extended to more systematic analysis in the practice phase. This fact emphasises the importance of instructing knowledge appropriately, ready to application in controlling the system. As expected, in the second experiment, too, when acquiring knowledge had been successfully promoted control performance turned out to be positively related to the amount of implicit knowledge (at least for Linas relations which could be detected quite easily). Since comparable positive correlations also occurred with knowledge acquisition and control performance in the early practice phase, Preußler corroborates the interpretation from correlation analyses (e. g, Müller, 1993, Funke, 1992b) that knowledge precedes and determines subjects' coping with the control task. She yet emphasises the importance of effective knowledge instruction. To a considerable extent effectiveness appears to depend on the time of instruction. Obviously, it is suitable to promote structural knowledge prior to its application in a control task so that the two processes of analysing and controlling will less interfere with one another.

A following study by Preußler (1998) attempted more detailed specifications of the suggested conditions under which induced structural knowledge will be predictive of success in a control task. Unlike in the previous experiment, Preußler was especially interested in the role of explicit structural knowledge; explicit knowledge was deemed more determinant than implicit knowledge because it enables subjects' making up and testing explicit hypothesis which might be helpful in control tasks. In accordance with the earlier findings emphasis was put firstly on early instruction of explicit knowledge (before the control task) and on even more application-oriented instructions.
Application-oriented promotion of structural knowledge in an experimental group meant a practice phase involving a graphical structural diagram for transparency combined with practice tasks: Goal values had to be attained by particular manipulations; the task lasted until participants themselves had found out correct solutions. In a control group by contrast structural diagrams were omitted and the same practice tasks could be finished without finding the correct solutions. The experimental procedure comprised two subsequent control tasks, one learning phase after the practice phase, then after some delay a second control task, the transfer phase. In total, 56 Bayreuth University students took part in a first experiment and another 54 students in a second experiment. All of them worked on different Linas implementations.
Results from the first experiment suggested supporting effects of the application-oriented treatment on structural knowledge (measured by the pair task) and performance: Struc-

tural knowledge of the experimental group, after the first control task already, was found to be significantly higher than with subjects of the control group. Interpreted as a consequence of enhanced and successfully applied structural knowledge, in both the learning phase and the transfer phase the experimental group outperformed the control group. Unlike the control group, the experimental group displayed “positive transfer”, i. e. in the transfer control task right from the beginning they performed equally well as at the end of the first learning control task. Concerning the relation between structural knowledge and control performance, as expected, positive correlations were revealed, yet only for problem solving in the transfer task. The partly deviation from expectations as to the learning task cannot fully be interpreted. However, unlike in Putz-Osterloh’s experiment (1993a, 1993b; see above) there is at least evidence that subjects’ control performance will benefit from induced structural knowledge in the first control task already instead of deferred benefits which are revealed but on a transfer task.
Preußler’s second experiment dealt with the question whether the enhanced control performance of the experimental group results from the mere fact that (some kind of) knowledge is instructed or whether successful control performance is promoted by the particular structural knowledge implied in the transparency condition. For this purpose the experimental group (receiving an almost identical treatment as in the first experiment) was compared to a control group receiving a training on specific, more concrete knowledge about isolated effects of intervention in the practice phase.
Obviously, confirming the author’s expectations, structural knowledge proved to be superior in promoting control performance. Although specific interventional knowledge might, of course, not be regarded as futile to control performance, evidence occurred that the practice on reaching isolated goals in the practice phase might have interfered with the successful coordination of these goals as required to system control. Additional analyses showed that less time was required to pass through the training on abstract knowledge (experimental group) as to the training of specific interventional knowledge (control group), suggesting that the application of structural knowledge is not merely more successful, but also more economic.
To summarise, the later findings of Preußler (1998) partly reconcile experimental investigation with the findings of correlation analyses claiming positive relations between knowledge application and knowledge acquisition. Provided that knowledge is acquired prior to system control in an application-oriented context, the equivalent positive correlations as in a posteriori analyses will appear.

The quality of knowledge and knowledge instruction. Studies on the impact of transparency made obvious that in general appropriate knowledge and appropriate ways of instructing knowledge will enhance the application of this knowledge in control tasks. Some questions, however, remain: With respect to the type of knowledge Preußler (1998) suggested that promoting structural knowledge is most helpful in problem solving whereas specific interventional knowledge has less beneficial effects. Is this necessarily the case? Additionally, one might consider the way in which the acquisition of (structural) knowledge is supported. Early application-oriented learning seems to facilitate later control performance (Preußler, 1998) – but maybe there is more to an effective instruction or tutorial?

For systematically comparing different modes of knowledge instruction Kluge (2003) designed an experiment involving the DYNAMIS system COLORSIM. COLORSIM, a system of the graphical presentation format, is made up of three abstract input variables (X, Y, Z) and three output or goal variables representing the names of colours ("yellow", "black", "green"). In the most simple realisation output variables are affected by four basic relations and one instance of eigendynamic; the most complex realisation includes two instances of eigendynamic as well as two side effects in addition to the four basic relations. In Kluge's experiment three degrees of connectivity – manipulated between subjects – gave rise to three experimental conditions: low, medium and high task difficulty.
Knowledge instruction as well was realised by means of three treatment conditions: explanatory screen mask, guided exploration and a combination of the two former instructional types. The main difference between the explanatory screen and guided exploration is the extent to which subjects become actively involved in the process of acquiring structural knowledge. While guided exploration requires active exploration, testing self-constructed hypotheses and independent reasoning,[8] the explanatory screen mask but presents and explains information to be received and analysed, yet very comprising information; besides graphical displays of structural diagrams verbal descriptions and corresponding numerical equations are provided so that the system's algorithm can be explained in successive steps.
Based on the statistical results from a sample of as many as 496 subjects Kluge concluded that none of the three instructional conditions generally proved superior to another. Effectiveness rather seemed to depend on the level of task difficulty. When the scenario had been classified as simple subjects of all three instructional conditions controlled COLORSIM equally well; only knowledge acquisition was reduced for participants confronted with guided exploration as compared to control subjects. Regarding medium task difficulty the combination of guided exploration and the explanatory screen turned out to promote both knowledge acquisition and control performance in a more effective way than guided exploration without additional explanatory elements. As the author assumes, when dealing with simple problems self-employed learning might be helpful and successful, but with more complex problems the advantages of self-instruction decline relative to the benefits of objective explanations. For high task difficulty each of the three instructional modes revealed deficits that might, according to Kluge, only be compensated for by further support such as leaving more time to cope with the complex problem.

The question whether structural knowledge in CPS is most important relative to other kinds of knowledge has been studied by Schoppek (2002). Schoppek promotes the theory that in general both abstract causal knowledge, i. e. structural knowledge, as well as specific interventional knowledge named input-output knowledge may be relevant to CPS. Yet the size of the complex system should determine which type of knowledge plays a dominant role. Analysing previous studies (involving both scenarios of the DYNAMIS approach and other scenarios) Schoppek found that in scenarios implying but a small number of possible solutions problem solvers seemed to acquire input-output

[8]Guided exploration is about equivalent to the instruction of testing hypothesis in studies on the effects of systematic rule-induction (see Vollmeyer, Burns, & Holyoak, 1996).

knowledge spontaneously. This kind of interventional knowledge obviously sufficed the demand of controlling the system. In contrast, for large systems making it impossible to store isolated combinations of input and output values to a sufficient degree subjects tended to develop structural causal knowledge even if they had not been instructed to do this.
Schoppek's argumentation, however, goes further and – as the conclusion of his experimental investigation – states that beyond structural knowledge and specific knowledge of input-output relations a third type of knowledge might come into play, operative or strategic knowledge. This kind of knowledge is defined as "knowledge about how to proceed in order to accomplish a task". Strategic knowledge can imply aspects of procedural input-output knowledge, but it may as well comprise quite abstract representations about a sequence of operator steps.
Which experimental evidence supports Schoppek's concept? With respect to hypotheses and general procedure the study Schoppek conducted on the impact of structural knowledge resembles previous studies on transparency (Putz-Osterloh, 1993a, 1993b) and enriched tutorials in promoting structural knowledge (Preußler, 1996, 1998). In a between subjects design 80 students studying at the University of Bayreuth controlled LINAS, preceded by a learning phase of either one of two conditions: Subjects of the experimental group passed through a computer tutorial which guided them to analyse effects of input variables; subjects of the control group explored the system and tried to reach goal values.
In accordance with Putz-Osterloh (1993a, 1993b) it was found that on the average participants of the two conditions controlled the system equally well although subjects of the experimental group had gained more structural knowledge. Following Preußler's earlier interpretation (1996, 1998; see above) one should assume that enhanced structural knowledge possibly was not available to successful use in the control task (although, in fact, the tutorial was administered prior to controlling the system in an application-oriented context). Schoppek's interpretation yet is partly different: Instead of "blaming" the experimental group for inert structural knowledge he points at knowledge acquisition among subjects of the control group. Due to early experiences with the dynamic system control subjects might have gained and later applied strategic knowledge which compensates for the enhanced structural knowledge of experimental subjects. Since even in a transfer task control subjects without a tutorial on strategic knowledge performed equally well as the experimental group[9] impacts of specific knowledge about input-output relations cannot explain the equal levels of control performance neither can structural knowledge.

Instructed strategies, analogies, and the impact of goal specifity. Studies on the effects of structural diagrams and other tutorials have shown that in CPS methods exist which promote the acquisition of knowledge, structural knowledge in particular, and which sometimes positively affect control performance as well. On the other hand we have seen that structural knowledge might not be the only factor responsible for successful problem solving (e. g Schoppek, 2002). Hence when looking for supporting

[9]This finding obviously contradicts Putz-Osterloh's earlier results, claiming that on a transfer task promoted structural knowledge leads to increased control performance.

factors in the process of CPS further possibilities need to be taken into account: In this section, the impact of instructed strategies and analogies will be discussed as well as the impact of goal specifity, which influences problem solvers' spontaneous application of strategies. Not in all cases it can be figured out whether one of these methods primarily supports knowledge acquisition, control performance or both, leading us back to the disputed relation between the two task demands.

Strategies. Before experimentally inducing and manipulating problem solvers' use of strategic approaches researchers have been analysing strategies subjects employ spontaneously and have assessed these strategies with respect to their effectiveness and systematicity. Implied in the concept of the Dynamis approach, to gain knowledge in a Dynamis situation it is required to discriminate the effects of single input variables. This can be accomplished by varying the relevant input variable and keeping all other variables at a constant value of zero, a strategy which has been referred to as VOTAT (Vary One Thing At a Time). VOTAT is often considered as the most promising strategy to knowledge acquisition in a dynamic situation (see, e. g, Putz-Osterloh, 1993b, Vollmeyer & Rheinberg, 1998, Rollett, 2002). Accordingly, manipulating more than two inputs at a time is associated with unsystematic exploration. A more detailed discussion of the effectiveness of VOTAT and other strategies is provided in part three when strategies are considered from the perspective of problem solvers' characteristics (see the experimental analysis by Vollmeyer, Burns, & Holyoak, 1996). Eigendynamics can be best detected by doing without any intervention at all, leaving all input variables at the value of zero. Another possibility, yet less frequently employed, is to choose interventions that are equal in absolute value, but opposite in signs on two successive trials. In the case of no eigendynamics, after the second trial the initial state should be re-attained. Concerning the detection of side effects applying particularly large input values can be helpful to discriminate a basic input effect from a usually smaller side effect (Schulz, 2003).

Rollett (2002) experimentally analysed and compared a number of such spontaneously employed strategies on the base of data from 109 subjects in a first and 207 subjects in a second study. Applying the dynamic system Biology Lab (Vollmeyer, Burns, & Holyoak, 1996) different types of strategies were recorded and assessed as to their effectiveness in gaining structural knowledge. Highest – and highly significant – positive correlations between knowledge acquisition and strategy use were found with keeping constant one or two input variables out of three input variables in Biology Lab ($r = 0.51$). Zero interventions, too, yielded positive correlations with the amount of knowledge gained ($r = 0.35$). Negative correlations in contrast were associated with respect to employing many different input values ($r = -0.50$). Obviously, when trying to understand a dynamic system by strategic exploration less is more.

Not surprisingly, due to its prominence and effectiveness the strategy of VOTAT has become a central element in experimental research on strategy instruction. Vollmeyer, Burns, and Holyoak (1996) systematically instructed the application of VOTAT in a CPS task on the base of the Dynamis system Biology Lab. The employed version of Biology Lab comprised eight variables, four exogenous variables, four endogenous variables which are affected by five primary input-output relations and one instance

of eigendynamic. As implied in the cover story participants have to imagine they enter a biological laboratory in order to find out how certain water qualities in a water tank (temperature, salt, oxygen, current) influence the population of four species of sea animals (prawns, sea bass, lobster, crabs). Out of a total number of 60 participants (undergraduate students at the University of California, Los Angeles) 30 subjects were provided with explanations and examples how to use VOTAT in subsequent phases of exploration (three rounds), of control (one round) and transfer tasks (one round). The other 30 subjects received no instruction on systematic use of strategies.
Given free exploration without specific target values in the three initial rounds to be reached the author's strategy instruction obviously "worked": Throughout all three rounds of exploration about eighty percent of subjects' interventions could be classified as VOTAT strategies rather than the unsystematic strategy of changing all variables or other, less systematic strategies. In contrast, most participants of the non-instructed control group did not adopt VOTAT spontaneously.[10] The instructed group revealed higher levels of knowledge acquisition, slightly higher levels of performance in the first control task and especially increased control performance in the transfer control task.
The results from this part of the experiment confirm that instructing systematic strategies such as VOTAT indeed has beneficial effects on dealing with complex dynamic systems – provided that task demands are suitable to follow the VOTAT instruction. What, however, makes task demands suitable to applying systematic strategies?

Goal specifity. An attempt to answer this last question is already implied in the same study by Vollmeyer et. al. Besides the impact of strategy instruction the authors examined another feature of the exploration setting: the matter whether subjects should be informed about target values of the control task from the very beginning (goal specifity) or whether during the first phases of free exploration they should simply be asked to find out about the system as much as they can before they get to know the target values to be reached and maintained in controlling the system (unspecific goal condition). One possible conception is that specific goals, encouraging efficient means-end analysis of how to reduce the difference between an actual state and a goal state, might be a suitable condition for acquiring knowledge (Anderson, 1987). On the other hand, however, one might argue that specific goals and associated means-end analyses should rather disturb an essential precondition of knowledge acquisition (Sweller, 1988): The strategy of means-end analysis might interfere with problem solvers' systematic induction of rules which would otherwise, in the absence of defined goals, have taken place. This later view has been adopted by Vollmeyer, Burns, and Holyoak.
In order to test the hypothesis that goal-oriented strategies, i. e. means-ends analysis, interfere with other systematic strategies adapt to gaining structural knowledge (e. g, VOTAT) the authors had implemented goal speficity as an additional treatment factor

[10] This finding on the effectiveness of strategy instruction is hardly self-evident. Vollmeyer and Rheinberg (1998), e. g, attempted to manipulate VOTAT strategy instruction in the context of motivational influences and found that differential strategy use among an instructed and a non-instructed group did not occur but for the very beginning of a CPS task. In the later process of the task instructional effects on strategy use disappeared, consequently not affecting knowledge acquisition and control performance either.

within the experimental design. Within each of the two experimental conditions of strategy instruction half of the subjects were given no target values until the control task, the other half was informed about the target values during the three learning rounds already although it was made clear that their task was "learning as much as possible" rather than merely aiming at the goal values.
For analysing participants' use of strategies in the goal specifity condition the classification distinguishing VOTAT from changing all inputs and other strategies was supplemented by the category of a difference reduction strategy. Difference reduction, a goal oriented strategy, was diagnosed when observed systems' states incrementally approximated the goal values and when subjects successfully reached the goals in the exploration phases already. According to Vollmeyer and colleagues difference reduction implies a strategic approach fundamentally different from VOTAT.
Prior to statistical testing the authors expected that in the context of goal specifity participants would apply VOTAT only if strategies were instructed explicitly. In case of no systematic instruction combined with specific goals subjects should make predominant use of the goal-oriented strategy of difference reduction. The results went beyond this expectation as to the impact of goal specifity. Even when instructed on VOTAT participants showed a strong linear trend away from this strategy, starting with VOTAT application in 80 % of the cases in the first round of exploration and finishing with a frequency of about 20 % use in the third round. Use of the strategy of difference reduction markedly increased during the three exploration phases for both instructed and uninstructed subjects provided with specific goals.
Critically examining practical requirements in this experiment Schoppek (2002) has argued that, in fact, subjects aiming to reach the goal values had had no other choice than to omit the VOTAT strategy since in the employed version of BIOLOGY LAB it would be virtually impossible to reach the goals by manipulating one single input variable. In a replication study he partly changed task demands and system characteristics to dissolve the confound between strategy instruction and goal specifity finding that subjects made use of VOTAT in spite of goal specifity just as Vollmeyer et al. had expected first. Although it thus remains disputable whether specific goals impair the use of instructed strategies as well at least in the context of no explicit strategy instruction spontaneous application of strategies seems to be affected by specific goals. What does this mean to knowledge acquisition and control performance?
Vollmeyer, Burns, and Holyoak showed that, as expected, participants gained more accurate knowledge about the dynamic system when no specific target values had been announced in the initial phases of learning and exploration. With respect to control performance in the learning task goal specifity did not give rise to significant increments or decreases. One might suppose that input-output knowledge related to means-end analysis in case of goal specifity has comparable effects on controlling as the enhanced structural knowledge when no specific goal is given. In the transfer task, however, subjects who had freely and systematically explored BIOLOGY LAB in the unspecific goal condition proved superior in controlling the system. This effect has been interpreted in terms of the subjects' comprising structural knowledge. Referring to Sweller (1988), Vollmeyer et al. conclude that "general problem solving methods applied to a specific goal foster acquisition of knowledge about an isolated solution path but do not provide

an effective way of learning the overall structure of a problem space" (p. 75).

Partly intended as a replication of these findings, Vollmeyer and Burns (1996) attempted a closer examination of mechanisms involved in the process of knowledge acquisition under the condition of both specific and unspecific goals. Following their hypothesis they experimentally compared the impact of goal specifity to another situational influence in CPS which is assumed to have similar effects: instructing subjects with explicit hypotheses to be tested vs. not instructing subjects. The theoretical notion behind this procedure goes back to Klahr's and Dunbar's dual space theory (1988) according to which learning can be guided by either one of two distinct processes: by explicitly forming hypotheses about possible system characteristics and then "testing" these hypotheses in terms of experiments (predominant search in a hypothesis space) or by first conducting experiments about system characteristics in order to induct rules or hypotheses afterwards (predominant search in an experiment space). Searching in the space of hypothesis is associated with greater systematicity and hence with greater knowledge acquisition than searching in the space of experiments that may sometimes appear quite haphazard.

Vollmeyer and Burns assumed that in practice hypothesis search and resulting knowledge acquisition should be encouraged, of course, by providing subjects with an explicit hypothesis to be tested when dealing with a dynamic system, but that not providing specific goals in the dynamic system should have comparable effects. These two factors, the instruction of an explicit hypothesis vs. no hypothesis instruction, and goal specifity vs. no goal specifity, made up an experimental design including 15 subjects per group, a total number of 60 subjects. Participants, students of the University of California, Los Angeles, dealt with BIOLOGY LAB in an experimental procedure equivalent to the authors' previous study. Instruction of an explicit hypothesis was realised by naming one hypothesis concerning a defined instance of eigendynamic as well as one hypothesis concerning a numerically defined input-output relation; these hypotheses were assigned to a (fictive) scientist.

With respect to goal specifity the effects found by Vollmeyer et al. (1996) could virtually be replicated: Knowledge acquisition measured by structural causal knowledge was reduced in the condition of a specific goal[11], suggesting again that specific target values prevent problem solvers from systematic searching in an hypothesis space but make them apply goal-oriented strategies directly aiming at the target values. As expected, the instruction of an explicit hypothesis, too, tended to induce better knowledge acquisition and higher achievement in a prediction task than if no hypothesis had been presented. Deviating from the effect of goal specifity, as to system control subjects of the hypothesis condition also outperformed subjects who had not been given an explicit hypothesis. In general, however, it appears that unspecific goals and the presentation of hypotheses to be tested affect problem solving in a similar way, both encouraging subjects to systematically induct and scrutinise rules.

Closer analyses of the data showed that enhanced control performance with subjects given a hypothesis was not confined to the variables whose effects were stated in the hypothesis. Yet to some extent better prediction scores and better structural knowledge

[11] Only as to the measure quality of prediction which depends on more concrete input-output knowledge no impairing effects of goal specifity were found.

gained by this group could be assigned to the information that was implied in the hypothesis. In order to limit the scope of this alternative explanation a second experiment was conducted, involving 236 participants. Three treatment conditions were realised: An experimental group instructed with the correct hypothesis, another experimental group instructed with a false hypothesis and a control group which received comparable information about a particular relation within the dynamic system, yet not formulated as a fictive scientist's hypothesis.
Statistical analysis showed that on all relevant dimensions subjects instructed by an explicit hypothesis performed better than subjects of the control group, even if the hypothesis-instructed subjects had been dealing with false information. Subjects given a false assumption did not generally perform worse than those given the correct information. According to Vollmeyer and Burns, especially this last finding emphasises that rather the mere instruction to test an assumption than the actual information implied in this assumption makes problem solvers induct rules and test their own hypotheses beyond the one given in the instruction.

Analogies. A final note concerning supporting factors in acquiring knowledge about dynamic systems refers to the instruction of analogies. Effects of analogies have rarely been studied in the context of CPS, hence the work done by Schulz (2003) in an unpublished diploma thesis might represent a pilot study in this domain. Analogous reasoning, a prominent concept realised in intelligence diagnostics, requires a person to transfer knowledge structures from a known, familiar domain to another, hitherto unknown domain of comparable structure, but different contents. As with the instruction of explicit hypotheses the cognitive demands involved in processing analogies, too, can be associated with increased search in a hypothesis space. Schulz thus assumed that instructing analogies in a CPS task would facilitate the acquisition of structural knowledge. For experimental testing an abstract Dynamis scenario named Wits, consisting of two endogenous and two exogenous variables was employed in an internet experiment. Three between subjects conditions of analogy instruction were manipulated: working on the system without any analogy at all, dealing with one analogy and dealing with three different analogies. All analogies were derived from familiar every day contexts such as the context of an ecosystem.
Results based on the data of 53 participants revealed a marked, yet not significant effect towards superior knowledge acquisition of subjects instructed with analogies. Somewhat unclear and different from the author's expectation the group provided with only one analogy even performed better than the group provided with three different analogies. On the whole, however, Schulz concludes that analogies obviously have beneficial effects on acquiring structural knowledge about a complex dynamic system.

3.3 Person characteristics

In the first two parts we have dealt with the role of system and task characteristics in CPS. Differing levels in performance even though subjects work on exactly identical problems under identical conditions make clear that it is not the dynamic system as such nor the task demand taken on its own which determines how well we do on a computer-simulated CPS task. To a considerable extent our achievement rather depends on ourselves: the strategies we employ deliberately or by intuition without explicit prior instruction, our current motivation as well as generalised motivational tendencies and our relevant cognitive abilities.

3.3.1 Strategies and systematic learning

The section about supporting factors which may enhance performance in CPS has already revealed the benefits of systematic, strategic operations in this context. Not surprisingly, just as experimental inducement of strategies leads to increased control performance and system identification, the same occurs if problem solvers apply appropriate strategies spontaneously without preceding request.

Branke (1991) conducted an experiment which involved 42 university students working on a Dynamis simulation named Korallenriff (coral reef); in addition to standard measures of problem solving abilities she recorded and classified the application of strategies as a personality factor and came to the conclusion that employing strategies is significantly related to successful problem solving. The more strategic the approach, the more knowledge will be gained and the better control performance will be.
Similarly, Putz-Osterloh (1993b) found that high increases in performance were associated with strategies classified as effective – especially strategies of selection – whereas low increases in performance were associated with less effective strategies, i. e. changing all inputs in the same trial. Not quite as expected, in Putz-Osterloh's experiment this effect could only be revealed when subjects had been promoted in gaining structural knowledge by means of transparency. A control group without additional information about the system's structure seemed to increase performance both in the case of effective as well as ineffective strategies. Satisfying explanations cannot be provided.
The particular relevance of VOTAT, the strategy of manipulating but one single input variable on a trial, has been highlighted in an above discussed study by Vollmeyer, Burns, and Holyoak (1996). VOTAT is compared and contrasted to the strategy of "changing all variables in a haphazard way" and a heterogenous collection of other strategies. Problem solving records of 36 students (studying at the university of California, Los Angeles) working on Biology Lab showed that a score on strategy systematicity was highly positively related to the accuracy of knowledge acquisition ($r = 0.76$) and control performance. While subjects employing VOTAT clearly performed best though not perfect, subjects characterised by haphazard strategies seemed to be impaired in structural knowledge, control performance as well as achievement in a prediction task.

Rollett, too, corroborates the view that individual differences in applying strategies help to explain the frequently observed large variances in problem solving performance. Rollett's experimental studies on the effectiveness of specific strategies (see the section about instructed strategies) are supplemented by analyses on the benefits of information utilisation. The term information utilisation refers to the question which and how much information participants – when dealing with a complex problem – actually take into consideration as compared to the type and amount of information participants might make use of in case of expertise. Practically speaking, the "experts'" utilisable information is rated for each subject and each episode of intervention separately by

analysing specific interventions and the resulting input and outcome states.
Correlation analyses based on samples of a 109 subjects in the first study and 207 subjects in a second study showed significantly positive correlations between the assumed experts' information use and participants' information use (correlation coefficients ranging from 0.56 to 0.29). Since the highest coefficients were found for information utilisation in the first of several learning rounds one may conclude that problem solvers at the beginning of their task make use of available information most efficiently whereas in the later process of problem solving efficient use of information partly decays, possibly due to further cognitive demands.
Combining the two concepts of strategic operating and information utilisation a problem solvers' typology has been Rollett's major contribution to the research on individual differences in CPS. Subjects are classified on two dimensions: on the dimension of strategy use as either insufficient, sufficient or efficient users and on the dimension of information use as either belonging to the lower, the medium or the upper third among other performers. Frequency analyses on the resulting (nine) combinations revealed that a majority of subjects characterised by efficient strategy use made highest use of available information; only a minority of them made lowest use of information. In turn, insufficient strategies were found primarily with subjects whose information use was assessed to be in the lower third. Obviously, efficient use of strategies and information coincide to some degree.

In her above mentioned study, Branke (1991) assessed that only half of the sample's participants preferred a strategic approach to the problem situation. In Putz-Osterloh's experiment (1993b) even as many as two thirds of the subjects could be characterised by employing ineffective strategies. The analyses by Vollmeyer and colleagues (1996) showed that in a first round of dealing with the dynamic system Biology Lab again two thirds of the subjects started exploring the system by least systematic haphazard strategies, but after three further rounds the share of unsystematic strategies declined to about 20 %. More than half of the problem solvers (58 %) rather made use of VOTAT in the later stages of exploration. As it seems, the use of systematic strategies will be promoted by growing experience with the dynamic system.
Why, however, do problem solvers still dismiss or simply not apply strategic operations in a dynamic computer-simulated task? To anticipate the subsequent sections, we will keep in mind that close relations exist between intelligence and exploration skills (Kröner, 2001) and that motivation, too, plays a major role in applying strategies (Vollmeyer & Rheinberg, 1998; Rheinberg, Vollmeyer, & Rollett, 2001). Yet an earlier study by Fritz and Funke (Fritz & Funke, 1988) suggests that the use of strategies in CPS might as well depend on some specific learning abilities not covered by overall levels of intelligence.

The authors examined problem solving performance and the use of appropriate strategies with a clinical sample of adolescents having "minimal cerebral dysfunctions" (MCD) which are strongly associated with learning difficulties at school. Out of 53 adolescents, 14 displayed a stable MCD symptomatic, 17 – the group of potentially affected adolescents – had once been given a diagnosis, but did not confirm it, another 16 adolescents had no MCD diagnosis at all, thus serving as a control group. All participants worked on a simplified version of Funke's Ökosystem (Funke, 1985), a dynamic system including three exogenous and three endogenous variables, one instance of eigendynamic and no

side effects or delayed feedback.
It was hypothesised that in spite of their overall high intelligence subjects having MCD would turn out to be inferior in strategic operating. Statistical analysis failed to reach significance, yet the results showed a tendency towards the expectations. Various strategies of CPS occurred in both the MCD groups and the control group, however, not equally distributed. Whereas subjects of the control group frequently and successfully employed zero intervention strategies and isolated manipulations of one single exogenous variable, strategies most adapt to gain structural knowledge, subjects of the MCD group more often tended to manipulate all three exogenous variables at a time, which hardly enables the detection of isolated effects. From this characteristic difference the authors inferred insufficient discriminatory abilities of participants having MCD.[12] Lowered integrational abilities, too, were assumed since, compared to subjects of the control group, those having MCD or being potentially affected required more time and experience to acquire knowledge, i. e. to form an integrated structure of knowledge.
Interestingly, despite differing strategic approaches performance levels were about equal among the three groups. MCD tends to be related to impaired strategic operations and strategic operations definitely affect the process of problem solving as we have seen, but there must still be other factors relevant to individual differences in this domain.

3.3.2 Motivation

It has widely been accepted that (at least some) motivation is necessarily required for achievement in cognitive tasks. In a few experimental studies (e. g, Funke, 1992b) measures of initial or current motivation have been implemented in order to ensure that on the average participants are equally well motivated among different experimental conditions.[13] Yet the majority of investigations appears to do without motivational measures of control, a fact which is not only due to economical considerations. The particular difficulty of motivational records concerns the fluctuating nature of current motivational states: Supposed an experimenter asks his or her subjects about some defined aspects of motivation, say, interest in the task and expectations of successful outcomes, how will the experimenter know whether the subjects' self-assessments remain valid over the course of the task's duration, over at least one hour and often more than that? Some facets of motivation, e. g, interest, which may appear dominant in the beginning, may decrease or disappear, while other facets come into play which initially have not been recorded at all, e. g, finishing one's task quickly not to miss a later appointment (compare Vollmeyer & Rheinberg, 1998). As Vollmeyer and Rheinberg did in their study discussed below, researchers can, of course, employ brief intermittent measures of present motivational states, yet being aware that the records might disturb the process of learning and CPS.
Another perspective in examining motivational impacts in CPS is to consider aspects of

[12]Concerning motivation adolescents of the MCD group revealed significantly higher failure motivation, i. e. fear of potential failure. As we will see below, anticipation of failure as well should impair the application of systematic strategies (see Vollmeyer & Rheinberg, 1998).

[13]The demand of comparable motivational levels will not necessarily be accomplished as Funke's findings show: Initial motivation already was lower for subjects who dealt with a system of merely numerical presentation than for subjects who worked on an equivalent system with graphical display.

personality which are related to current motivational states, but are assumed to be more stable over time and hence less affected by the hazards associated with current motivation and intermitting records. The term motivational orientation or goal orientation has been introduced to define relatively enduring motivational tendencies, an individual's "tendency to favour specific types of goals, outcomes or consequences over some others" (Niemivierta, 2002). Unfortunately, according to Görn et al. (2001), experts have not yet fully agreed as to the question to what extent motivational orientations display stable traits of personality or to what extent they are still related to fluctuating motivational states.
In the present paper we will try to consider the impact of both motivational states and trait dispositions on CPS. The four studies discussed in this section especially focus on the question which motivational factors interact in which way with relevant cognitive variables in problem solving. As Vollmeyer and Rheinberg (1998) state, motivation per se does not affect cognition but is mediated by the frequency and duration, by the quality of learning activities and the learner's functional state such as his or her concentration.

With regard to motivational states in CPS Vollmeyer and Rheinberg (1998) have examined the impact of two specific factors: interest in the task and confidence of success vs. fear of failure. In preliminary examinations these two facets of motivation had turned out to be crucial specifically to the context of computer-simulated dynamic tasks. Hence, for their experiment, Vollmeyer and Rheinberg recorded the two factors both as part of a questionnaire intended to assess initial motivation and by means of brief questionnaires assessing motivation parallel to a dynamic problem solving task. The intermittent questionnaires contained only one item each for task interest and confidence of success: "I am still enjoying the task" and "I am sure I will find the correct solution". In order to elucidate how assumed motivational effects are mediated the authors added two measures characterising learning activities: participants' concentration on the task, especially "effortless concentration" which is associated with productive learning, secondly the systematicity of applied strategies as can be inferred from the protocol of input and output states. Effortless concentration was assessed in a one-item-scale questionnaire.
48 students of the University of California, Los Angeles, took part in Vollmeyer's and Rheinberg's study. Subjects worked on a relatively complex version of the Dynamis system Biology Lab whose cover story refers to a virtual biological laboratory; within the "biology lab" participants have to find out how three chemical factors (salt, carbon, calcium), the exogenous variables, influence the quality of water in a tank with respect to three indicators (oxygenation, chlorine concentration, temperature), the exogenous variables. Three rounds of mere exploration, each consisting of eight intervention trials, were conducted, one subsequent round was assigned to system control and accomplishing defined goal values.
Regarding the two motivational factors, unfortunately, only the factor confidence of success vs. failure motivation proved stable enough to more detailed analysis. Subjects' self-evaluations of initial interest in the task seemed to coincide too little with later ratings of the task's attractiveness, so that this factor was dismissed.
Path-analytical analysis of the remaining cognitive and motivational factors revealed two indirect impacts (paths) and one direct impact subjects' confidence of success has on the quality of CPS. Indirect relations between confidence of success were firstly found

to be mediated by the systematicity of strategies applied: The more confident subjects feel that they will succeed the more systematic strategies they will employ, an effect which yet only became noticeable as late as the third round of exploration. Systematic strategies in turn are positively related to the acquisition of knowledge and this again has positive effects on the application of knowledge, leading to enhanced control performance. Secondly, concentration appeared to be a mediator: The more confident about successful outcomes, the higher participants scored on effortless concentration. Interestingly, in Vollmeyer's and Rheinberg's model concentration revealed an enhancing effect on control performance without enhancing knowledge acquisition as well. From this fact the authors conclude that effortless concentration due to good motivation displays its beneficial effect only when knowledge actually is applied; no explicit knowledge structures need to exist prior to application (see Vollmeyer & Rheinberg, p. 20). The third path-analytical finding concerns a direct positive of impact confidence of success vs. fear of failure on knowledge acquisition. Obviously, high confidence of success is associated with increased knowledge neither as a specific result of concentration or systematic strategies, but possibly fostered by some other mediating factors we do not know yet.

Further specifications as to the interaction between current motivational states and cognition in CPS have been provided in a subsequent study by Rheinberg and colleagues (Rheinberg, Vollmeyer & Rollett, 2002). Motivational factors of research interest were probability of success, anxiety, which corresponds about to fear of failure, interest in the task and challenge, i. e. whether problem solvers feel that a task is a challenge to them. These four factors formed a global score on initial motivation. Besides motivation, in this study relevant cognitive ability was examined as measured by the series completion subtest from the Intelligenz-Struktur-Test (Intelligence-Structure-Test, I-S-T, Amthauer, 1970)[14]. For cognitive measures characterising the process of CPS and its quality the following were chosen: quality of goal achievement, quality of system identification and a score on strategy systematicity.
107 students from the University of Potsdam and from local high schools were selected to participate. The general procedure of the experiment was comparable to the above study; the Dynamis scenario applied was an almost identical version of Biology Lab. The main difference of Rheinberg's, Vollmeyer's and Rollett's study as compared to the previous concerns its methodological approach. Instead of applying path analysis the authors ran cluster analyses, i. e. they tried to gain an insight into the relations between initial motivation, ability and goal achievement by searching for different types of learners who reveal characteristic patterns of motivation, ability and achievement. Five such different types (groups or clusters) could be distinguished: Firstly, there were subjects who – in line with theoretical expectations – scored high in goal achievement, in relevant initial ability and motivation. These were termed the optimal learner type. The mirror image of the optimal learner type scoring low in all three variables, too, was found, and named the poor learner type. A third class of subjects proved to be relatively low in performance despite high initial ability; as subjects' motivation, however, was low, performance deficits seem to have a profound explanation. Concerning these learners, Rheinberg and colleagues speak of the underachiever type.

[14]In the series completion subtest participants try to detect regularities inherent in a series of numbers and complete the series according to these regularities. The test focuses on logical numerical abilities.

Less straightforward patterns of motivational and cognitive variables occurred for subjects of the two remaining clusters: Both of these groups showed about average ability and initial motivation, yet one group performed far worse than the other. What might explain this fact? As an analysis on strategic operation suggested, the better performers were those who acted more strategically and systematically. Hence the authors added a cluster of systematic learners vs. a cluster of unsystematic learners to their typology. They conclude that obviously both motivational aspects as well as cognitive ability, strategy systematicity and still additional factors need to be combined when examining the variances of individual performance in a CPS task. Rheinberg, Vollmeyer and Rollett also note that clustering subjects according to characteristic patterns provides a useful description of motivational influences, but not an explanation in terms of cause-and-effect-relations.

In contrast to relatively fluctuating motivational states goal orientation as defined above deals with more enduring traits of personality that determine which goals or expected outcomes make us put effort, time and concentration into learning activities such as a CPS task. Two "classical" learning goals, sometimes considered as exclusive goals, have become prominent in psychological research: The goal of enhancing one's competence and the goal of demonstrating one's competence. The former motivational orientation has been named ego orientation or performance orientation, the latter has been named task orientation or competence orientation (see Nicholls, 1984; Dweck, 1986, 1989). More differentiated goal orientations have been suggested by Niemivierta (2002) who adds achievement goals, i. e. the goal to succeed, performance-avoidance goals, i. e. the goal to avoid situations of potential experiences of failure and avoidance goals, i. e. the goal to get off with as little effort as possible to the distinction of performance goals and learning goals.

Certainly, any of these goals can affect a learner's performance in the domain of CPS. Which, however, will provide most suitable conditions for successfully coping with a task? Dweck (1986) as well as Nicholls (1984) suggest that goal orientation considered on its own has no marked impact on problem solving performance. Task oriented learners who are particularly interested in the task itself should do generally well when dealing with a complex problem. Those, however, whose ego is – due to performance orientation – more involved should rather depend on the level of their abilities as they themselves perceive it. An ego-oriented learner who is confident in his or her abilities will perform just as well as a task-oriented learner of comparable abilities; yet the ego-oriented learner will prove inferior in performance if belief in his or her capabilities is poor (see Görn et al., 2001).
According to Görn, Vollmeyer and Rheinberg (2001), this interaction between motivational orientation and self-evaluation of abilities had been demonstrated in prior experiments applying differential instructions to manipulate either learning or performance goals as experimental factors in between subjects designs. Görn and her colleagues advocated another approach: Since they conceived motivational orientation rather as a trait of personality than as a transient state to be experimentally induced they examined the same interaction hypothesis by measuring goal orientations in motivational questionnaires.
113 school students from upper grades, mostly eleventh graders, took part in the ex-

periment. For testing in classrooms the CPS task was administered as a paper and pencil version of Biology Lab. Pupils had to imagine they were medical researchers in a laboratory and had to find out how three types of medication named A, B, and C, the exogenous variables, affected each of three body substances, the output variables named serotonin, thyroxin, and hystamine. Corresponding to six learning phases in the computer-based scenario six different states of the system were presented subsequently on six sheets of paper. These had to be analysed in order to gain structural knowledge as measured through causal diagrams. In a final equivalent of the application phase subjects calculated how exogenous variables had to be manipulated so that defined outcome states of the endogenous variables would result. Success in problem solving was analysed with regard to knowledge application and a score comparable to control performance in computer-simulated versions. Perceived subjective failure or success was recorded by brief self-ratings after each of the six sessions. The above hypothesis of an interaction between motivational orientation and self-evaluation of failure or success could not be confirmed. The authors assume that this effect is less prominent when goal orientation is examined as a personality factor than when it is experimentally induced.
A second hypothesis concerned the relation between performance and learning goals: Does it seem appropriate to assume performance and learning goals as non-overlapping, exclusive characteristics of learners? Thinking of goal orientation rather as a two-dimensional construct of personality, Görn, Vollmeyer and Rheinberg classified subjects according to four categories: task-oriented learners scoring high only on task orientation, ego-oriented learners scoring high only on ego orientation, high indifferent learners scoring high on both orientations and low indifferent learners scoring high on neither orientation. It was predicted that high indifferent learners would be most successful in a CPS task because two goals, relative to only one, might enhance the beneficial impact of motivation. Following the same logic, low indifferent learners were expected to perform worst, i. e. even worse than ego-oriented subjects who care at least for demonstrating competence as their dominant goal. While high indifferent learners indeed turned out to perform best, unexpectedly low indifferent learners, too, did well on their task, a finding which remains unclear. In spite of this, according to Görn and colleagues we can at least suppose that the bipolar distinction of learners as either task-oriented or ego-oriented appears too general.

Niemivierta (2002) continued the research on goal orientation in CPS by means of two further approaches. With respect to subjects' evaluations during problem solving Niemivierta analysed not merely self-related evaluations of success or failure and test anxiety, but also subjects' situational appraisals. Secondly, he combined the trait-oriented notion of goal orientations (see Görn et al., 2001) with earlier experiments' practice to induce either task-involving or ego-involving learning conditions. The main question in Niemivierta's work is how habitual motivational orientation interacts with different instructional learning conditions with respect to situational appraisals and resulting performance in a CPS task. Examples of situational appraisals are self-efficacy, i. e. confidence to do well in a task, and claimed self-handicapping, i. e. the use of anticipatory excuses (like being ill or in a bad mood) when success might be threatened. Niemivierta examined situational appraisals, goal orientation and, of course, task performance (knowledge acquisition and knowledge application) in a sample of one 143 school

students[15], ninth graders from junior high schools in southern Finland. The students dealt with the computer-simulated dynamic system Med Lab, which is nearly identical to Biology Lab, each under one of two different instructional conditions. Half of the students, the task-involving condition, received task-focused instructions which requested subjects to work on the problem as hard as they could, so that the current version of Med Lab could be evaluated and revised. It was highlighted that the students would not be tested with regard to individual successful performance. The other half of the students, the ego-involving condition, received performance-focused instructions; these obviously focused on individual performance as students were told that a few days later, their teacher would announce the results.
It was hypothesised that subjects in the latter condition as compared to those receiving task-involving instructions would reveal higher levels of test anxiety, lower levels of self-efficacy and more claimed self-handicapping, especially if the students had been classified as habitually performance-oriented learners. Furthermore, performance in the Med Lab task was expected to be lower with participants of the ego-involving condition. Disconfirming the last expectation, levels of task performance did not differ significantly among the two instructional conditions. Neither did test anxiety seem to be affected by ego- vs. task-involving instructions; as one would guess, test anxiety was generally highest for participants reporting performance-avoidance goals, the goal to avoid situations of potential failure. Yet with regard to situational appraisals Niemivierta's assumptions were supported: Ego-involving instructions obviously led to lower reported self-efficacy or lower expected success, which may be interpreted as a self-protecting function in the ego-involving and possibly ego-threatening instructional context. While subjects with different patterns of goal orientations seemed to be comparable as to their overall situational appraisals, in the ego-involving condition more self-handicapping and less self-efficacy was reported when learners' scored high on ego orientation as a personality trait relative to habitually task-oriented students. Once again, the impact of different goal orientations and multiple effects in the context of CPS are illustrated.

3.3.3 Intelligence

Last but not least, our final section concerns the role of intelligence in CPS tasks. In research literature this issue has been discussed in rather controversial disputations. As Funke (2003) states, in early research, test intelligence has been regarded and examined as the major influencing factor on problem solving. Yet initial findings seemed to contradict both common sense and scientific hypotheses. An investigation by Putz-Osterloh (1981) applying tailor shop, a popular, non-Dynamis-based computer simulation, even suggested that no systematic relations at all existed between test intelligence and control performance in tailor shop. In fact, a tendency towards a negative relation occurred, i. e. participants scoring high in a traditional intelligence test did worse in controlling the complex scenario. Less striking, a following experiment (Putz-Osterloh & Lüer, 1981) revealed zero correlations between control performance and intelligence only if no additional information had been given to the problem solvers. In case of transparency, i. e. if the system's internal relations had been disclosed to subjects by means of a structural

[15] To later evaluation only the data of 100 subjects proved to be valid.

diagram, the authors found significantly positive correlations between the intelligence score and the quality of system control.
Hence the more intelligent the problem solver the more successful he or she will interact with a dynamic system, but this effect is mediated by transparency conditions. Why should this make sense? Following the author's interpretation working on a transparent dynamic system requires systematic analysis of given information prior to its application, a task demand which is relatively similar to the demands of traditional intelligence diagnostics. In case of intransparency – a typical feature of complex problems – participants actively search for task-relevant information, a demand not covered in intelligence tests. As self-guided search for information and analysis of given information require different abilities, success in a standard problem solving paradigm and conventional intelligence tasks may be unrelated (for summaries of the findings see also Funke, 2003).
In consequence, differential task demands and required abilities concerning these two domains have increasingly been the focus of attention. Presenting his concept of "operative intelligence" Dörner (1986) has highlighted the dynamic orientation as the main task feature specific to CPS. Unlike in static intelligence tests which cover participants' speed and accuracy abilities, working on complex dynamic systems additionally involves skills such as anticipation and consideration of temporal processes, setting up appropriate goals and subgoals (and occasionally modifying them in the course of the process), using successful and adaptive strategies to search for relevant information. Ecological validity, i. e. the proximity to "real" problems in the outside world is said to be much higher for complex problem computer simulations as compared to traditional intelligence tests.

On the other hand, at least some connections between problem solving and test intelligence cannot be denied. Starting with an experiment by Funke (1983), the view that scores in intelligence tests can predict the level of control performance has become reestablished. According to Beckmann and Guthke (1995) positive correlations between intelligence and achievement in problem solving could be revealed consistently (p. 178). Yet correlations appear too low to infer a direct impact of intelligence on the process of problem solving. Following Dörner's approach, Beckmann and Guthke assume a multitude of influential factors that mediate the effects of test intelligence. Transparency is one such factor (see above), and the same applies, e. g, to task difficulty or goal definition. Highest correlations between intelligence scores and control performance in CPS can be expected with problems of average difficulty (Beckmann & Guthke, p. 184). Concerning goal definition, well-defined goals in a problem solving situation make the demands more similar to demands of traditional intelligence tests than ill-defined goals (e. g, Strohschneider, 1991). As further examples adding to this list, potentially mediating effects of semantic embedding and learning ability were analysed in an experiment done by Beckmann and Guthke.
The researchers tested 92 school students successively on a CPS task (first session), two conventional intelligence tests (second session) and two comparable short-term learning tests (third and fourth session). Experimental manipulation as to semantic embedding was realised by assigning half of the pupils to a semantically embedded Dynamis system named Kirschbaum while the other half worked on Maschine, a Dynamis system identical in structure and parameters, but lacking semantic embedding. The measures

of academic intelligence comprised a subtest on analogies taken from the Amthauer Intelligenz-Struktur-Test (IST, Amthauer, 1973) and a reasoning task ("figure series"), the pretest of the Lerntest "Schlussfolgerndes Denken" (LTS 3, Guthke et al., 1983).
The results confirmed the authors' expectation that semantic embedding mediates the influence of test intelligence on control performance: Significant correlations between these two measures were found only if the complex problem situation was abstract. In case of semantic embedding intelligence scores could not predict control performance (for an equivalent finding see also Müller, 1993). This, however, obviously did not result from semantic embedding per se, but from generally impaired knowledge acquisition in the semantic context. As noted in the section about semantic embedding, semantics can lead to "sham confidences" which prevent participants from gaining real and useful knowledge. In turn, if hardly any knowledge is acquired by both intelligent and less intelligent subjects, except for ad hoc control there is no reason why anyone should be superior in knowledge application, i. e. in control performance.
The authors' second question aimed at learning ability and the comparability of complex problem situations and learning tests. The idea behind learning tests is to "record not only a subject's momentary performance in a one-time administration of a test procedure, as is done in the usual static intelligence test situation, but also the subject's responses to repeated, standardised questions that are built into the test" (Beckmann & Guthke, 1995, p. 186). Hence, the concept of a learning test appears to share some dynamic components with CPS tasks, although in learning tests more detailed and instantaneous feedback is given to participants. The two learning tests chosen for Beckmann's and Guthke's experiment were said to cover learning abilities that corresponded to the intellectual abilities measured by the two conventional intelligence tests. It was hypothesised that learning tests, sharing the dynamic feature with CPS, are better instruments of predicting knowledge acquisition in a complex situation than static intelligence tests would be. No effect was expected with regard to control performance. In general, statistical analyses confirmed the expectations. Only in case of semantic embedding learning tests and static intelligence tests were equally good or equally bad predictors of the amount of knowledge gained since this amount of knowledge was generally poor (see above). Beckmann and Guthke conclude that systematic relations between academic intelligence and performance in complex problem situations definitely exist. Zero correlations as reported in early research might have been methodological artefacts, e. g, due to impaired and omitted knowledge acquisition, the authors suggest. Existing correlations yet become more prominent if mediating factors such as semantic embedding or learning ability are revealed.

More recently, Kröner has studied the correlations between problem solving performance and test intelligence from a practical point of view. His aim has been to develop and validate a Dynamis system suitable to serve as a tool of intelligence diagnostics. Original and revised versions of MultiFlux, the graphically embedded computer simulation of a fictive machine, provided the base of three experimental studies. Control performance and knowledge acquisition in MultiFlux was compared to achievement in the Advanced Progressive Matrices (APM; Raven, 1958), a conventional intelligence test which demands logical reasoning in completing graphical patterns.
The first study, a pilot study involving a sample of 28 students, on the whole supported

Kröner's major hypotheses: Intelligent subjects performed better on the MultiFlux control task. They also tended to be superior in skilful exploration although, in part, (indefinite) factors other than test intelligence seemed to contribute to exploration skills. To reduce the influence of such unknown sources of variation and to rise the impact of intelligence on exploration in dynamic system the second experiment was conducted. 96 high school students worked on a revised version of MultiFlux. Indeed correlations between good exploration of MultiFlux and APM scores were found to be higher . The third study employing a further revised scenario finally was designed to show that the enhanced control performance of intelligent subjects is not merely the result of better knowledge acquisition (due to more skilful exploration); instead there should be a an additional direct and positive effect of test intelligence on control performance. The data of a 101 pupils (grades ten to twelve) supported this claim. Kröner resumes that close relations exist between achievement in a conventional intelligence test and the quality of dealing with a complex system, the correlations being high, though not maximal. The indicators of test reliability are considered satisfactory so that, according to Kröner, MultiFlux might provide a simulation-based tool of intelligence diagnostics in the future.

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