to help learners deal with the complexity of tasks, that is, to provide supports that enable them to deal with more complex content and skill demands than they could otherwise handle. Moreover, provided guidance and support should gradually decrease in a process of "scaffolding," as learners gain more expertise (e.g., Reiser 2004). ► Cognitive load theory (van Merriënboer and Sweller 2005) explicitly studies methods that might help to reduce the high cognitive load that is imposed by rich learning tasks. Van Merriënboer et al. (2003), for example, describe on the basis of ► four-component instructional design methods that might help reduce high cognitive load: (a) simple-to-complex sequencing of classes of equally difficult whole tasks, (b) working from worked examples to conventional problems, (c) just-in-time presentation of helpful information, and (d) provision of part-task practice for routine aspects of tasks.

With regard to learning outcomes, complex learning explicitly aims at ► transfer of learning, that is, the ability to apply what has been learned to unfamiliar problems and/or in new situations. The main assumption is that complex learning yields a highly integrated knowledge base, organized in cognitive schemas, which facilitates transfer (Gagné and Merrill 1990). On the one hand, particular types of learning tasks (e.g., goal-free problems, worked examples, completion tasks), which are carefully tuned to the current level of expertise of learners, contribute to the development of an integrated knowledge base and subsequent transfer performance; on the other hand, ► variability of practice should ensure that the whole set of learning tasks varies on all dimensions on which tasks also differ from each other in the real world, including surface features and structural features, to reach transfer (for an overview, see van Merriënboer and Sweller 2005).

Cross-References

► Cognitive Load Theory
► Four-Component Instructional Design
► Transfer of Learning
► Variability of Practice

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Complex Problem Solving

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Synonyms

Dealing with uncertainty; Dynamic decision making; Problem solving in dynamic microworlds

Definition

Complex problem solving takes place for reducing the barrier between a given start state and an intended goal state with the help of cognitive activities and behavior. Start state, intended goal state, and barriers prove complexity, change dynamically over time, and can be partially intransparent. In contrast to solving simple problems, with complex problems at the beginning of a problem solution the exact features of the start state, of the intended goal state, and of the barriers are unknown. Complex problem solving expects the efficient interaction between the problem-solving person and situational conditions that depend on the task. It demands the use of cognitive, emotional, and social resources as well as knowledge (see Frensch and Funke 1995).

Theoretical Background

Since 1975 there has been started a new movement in the psychology of thinking that is engaged in complex problems in contrast to simple problems. Essential impulses for this development came from external, shocking events like the oil crisis or the first analyses of the "Club of Rome" at that time, which showed the constraints of growth and which made humanity-threatening problem fields visible. Besides that, the dissatisfaction about the nonpredictability of relevant characteristics like professional, economical, or political success based on classical intelligence tests led to a search of alternative measurements for the assessment of the way humans deal with complex situations, a search for "operative intelligence," as it was coined by Dietrich Dörner.

As an alternative, the use of computer-simulated scenarios was proposed. Such "microworlds" allow experimental research of complex problems under controlled conditions (Brehmer and Dörner 1993). For example, the scenario "Lohhausen" (Dörner 1997) simulated the events in a fictitious village. The subject had to act as the mayor of a small city for simulated 10 years (essentially reduced to nearly 10 h of gaming time) and had to care about the well-being of the community and its financial wealth. For this task, the fictitious mayor could control the events and shape the town according to her or his visions. Based on the data from successful and less successful subjects in this scenario, interesting hypotheses about the conditions of success and failure in dealing with uncertainty and complexity have been formulated.

Since that early start of this research program with "Lohhausen" in the mid-1970s, numerous scenarios with varying extent and from different domains (e.g., economy, ecology, policy, technology) have been developed and applied in both basic and applied research. In the following sections, I will outline characteristics of complex problems, describe tendencies in research, illustrate empirical results, and discuss problems and perspectives of this approach.

Characteristics of complex problems considerably differ from requirements of simple problems. Five features have been differentiated traditionally (Funke 2003):

1. *Complexity of the problem situation.* Traditionally, complexity is defined based on the number of variables in the given system. Surely, this is only a first orientation for the estimation of problem difficulty, but additional characteristics permit more reliable assertions. Complexity demands from the problem solver a simplification through reduction to the essential.
2. *Connectivity between involved variables.* Needless to say, it is not the pure number of variables that is decisive for the workload on the problem-solving person, but the connectivity between these. Assuming that in a system of 100 variables every variable is connected to only exactly one other, the connectivity is lower than in a system in which *all* variables are connected to each other. For making mutual dependencies understandable, a model of the connectivity is required from the problem solver.
3. *Dynamics of the situation.* This feature explains the fact that interventions into a complex, networked system might activate processes whose impact was possibly not intended. A unique variant is the own (intern) dynamic ("eigen-dynamics"). It signifies that in a lot of cases the problem does not wait for the problem-solving person and his/her decisions, but the situation changes itself over time. Dynamic requires from the problem solver the consideration of the factor "time."
4. *Intransparency* concerning the variables involved and concerning the definition of the goal. In an intransparent situation, not all required information about variables and possible goals are given. Intransparency requires from the problem solver the active acquisition of information.
5. *Polytely.* In a complex situation, reaching goals can be complicated. Usually there is more than *one* goal in a complex situation that has to be considered. Conflicts due to antagonistic goals require the forming of compromises and the definition of priorities.

Two approaches concerning research with complex problems differentiate with respect to procedures and to goals:

- The *experimental approach*: "Systematic manipulation of scenarios." Essential features of this approach are the experimental manipulation of the stimuli (the complex systems) and its condition of presentation. Particularly the systematic manipulation of scenarios (or system features) became a characteristic of this approach: degree of connectivity, presence or absence of eigen-dynamics, or the degree of time delays show influences on knowledge acquisition (= identification of systems) and knowledge application (= control of systems).

- The *correlational approach*: "Search for interindividual differences." Essential features of this approach are the search for interindividual differences and the search for correlations of success and failure. Systems attributes were kept constant to see the space of behavioral possibilities. Additionally, individual trajectories through complex systems were analyzed and correlated with constructs like test intelligence, personality characteristics, and so on.

Important Scientific Research and Open Questions

Many empirical results for solving complex problems are reviewed by Funke (2003) in detail. Here, only selected but important results are presented. They are ordered by their focus.

With respect to *Personality Aspects*, general intelligence measured by tests seemed to be an inappropriate predictor for handling complex problems according to previous research. However, by today's knowledge it seems clear that specific components of intelligence (like processing capacity) are predictive for the successful handling of complex problems (Wenke et al. 2005). Besides that, there are several forms of knowledge (e.g., system knowledge, control knowledge, strategic knowledge) that have to be taken into account.

The role of motivational parameters becomes apparent in the fact that problems which are considered as more important get more attention (e.g., the different handling of a simulated epidemic situation based on deadly smallpox or innocuous influenza). As a consequence, there are changes in strategies of information processing. If really high-stake problems are dealt with, the search for risk-defusing operators increases.

Emotional effects find expression, for example, in "emergency reactions" of the cognitive system. After perceived failure of problem solving a decrease in intellectual level follows, which is accompanied by a tendency for fast acting and for degenerated hypothesis generation. Also, the emotion regulation during complex problem solving plays an important role. Experiments showed that complex problem-solving situations with negative feedback of results lead to a higher information retrieval and to a better performance.

With respect to *Situational Aspects*, according to early studies, transparency of a system leads to easier information processing and increasing efficacy of intelligence concerning the success of problem solving. However, this moderator function of transparency is questioned repeatedly by current research.

Passive observing of a system or active intervention are two situational requirements, which lead to different acquirements. While pure observing delivers structural knowledge about the problematic system, control knowledge arises out of intervention conditions (Osman 2010). An increase in training also leads to improvement under complex conditions. However, there are certain conditions (e.g., existence of time delays), which do not profit from it.

The semantic appearance of a system is very important, since several prior knowledge structures are activated and can be used. However, prior knowledge is not always beneficial, especially if activated prior knowledge fitting only on the surface does not correspond to deeper structures.

With respect to *System Aspects*, the type of feedback is important for the success in solving the problem. Generally one can say: the more indirect and delayed a feedback for a certain condition of the system, the more difficult the controlled intervention. Formal features of systems also have proven their influential status concerning identification (knowledge acquisition) and controlling (knowledge implementation) within the process of complex problem solving (for a review, see Osman 2010).

Problems within complex problem-solving research deal with the following issues:

- *Identifying the quality of solution.* A decision about the quality of simple problem solving is easily possible, because the criteria for success are transparent. For complex problems the situation is different, because mostly there are no obvious goal conditions. A one-dimensional evaluation is not possible in that case. Problems arise if success of handling complex problems is used for diagnostic statements about the acting person.
- *Context effects.* One of the most impressive abilities of human cognition is its enormous context sensitivity. Structural similar tasks are treated differently in different semantic contexts. Different contexts also become apparent in processing the same

requirements in different cultures. Cultural comparison does not mean changing between nations or continents, but could happen simply on the level of "subcultures." Assessing how variations in context lead to variation in strategies and subjectively constructed problem spaces within the process of problem solving might be an important task of future research.

- *Training and the question of domain specificity or generalizability.* The question of domain specificity of problem-solving activities is closely related to the issue of context sensitivity. In case of research in complex problem solving, the question is one of transfer of knowledge and strategies between specific scenarios. It is generally accepted that confrontation with different scenarios leads to an extension of the realm of experience – however, there are no empirical evidences. The simple repetition of processing the same scenario leads to learning effects, but training itself means more: the acquisition of strategic competences universally applicable. Finding rules for unpredictable situations could be the squaring of a circle. Concerning application aspects, there is a huge challenge of psychological research in problem solving.
- *Missing theory.* The major problem of current research is the lack of a firm theory about dealing with complex problems. It is not even clear if there is a need for another theory besides a theory for solving simple problems. Indeed a global theory of cognition that describes and explains dealing with *all* forms of problems is needed. But such a "unified theory of cognition" (Alan Newell) does not seem to appear on the horizon.

Perspectives. Within the major area called "psychology of thinking and reasoning," the exploration of complex problems represents a question that is of great significance beyond our discipline. Thereby, a chance appears to devote psychology on a basis of verified findings to a field of application within areas like politics and business consulting ("give psychology a-way"). For this reason, more intensive data pooling and the refinement of appropriate theoretical approaches are needed. Interesting developments could be expected in following areas:

- *Task and requirement analysis.* It seems profitable to undergo an analysis of requirements concerning the tasks set by the different scenarios. Thereby, one would get from blanket description to precise testimonies. Scenarios have to be analyzed in form and content. It has to be explained properly what is measured.
- *Characteristics of the problem-solving process.* Once the requirements are known, cognitive processes within the acting person can be focused in detail. Particularly the differentiation between implicit and explicit processes and their relation to the distinction between novice and expert problem solving could be of peculiar interest. Based on this research, training procedures could be designed. Existing dynamic scenarios contributed to this purpose already because of their differentiation between different forms of knowledge, of strategies, and of metacognition.
- *Heuristics.* It seems promising to transfer our knowledge about heuristics found in research on decision making to the field of complex problem solving. Possibly simple heuristics control the processing of complex problems, an idea which would be helpful for finding a global theory.

Cross-References

► Complex Problem Solving
► Learning and Thinking
► Problem Solving
► Simulation and Learning: The Role of Mental Models
► Simulation-Based Learning

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