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RESEARCH REPORT

Complex problem solving: a case for complex cognition?

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Abstract Complex problem solving (CPS) emerged in the last 30 years in Europe as a new part of the psychology of thinking and problem solving. This paper introduces into the field and provides a personal view. Also, related concepts like macrocognition or operative intelligence will be explained in this context. Two examples for the assessment of CPS, Tailorshop and MicroDYN, are presented to illustrate the concept by means of their measurement devices. Also, the relation of complex cognition and emotion in the CPS context is discussed. The question if CPS requires complex cognition is answered with a tentative "yes."

Keywords Complex problem solving · Operative intelligence · Macrocognition · Emotion · Complex cognition

Introduction

In the last 30 years, a new part of the psychology of thinking and problem solving emerged in Europe under the label of complex problem solving (CPS). This paper introduces into this field and provides a review of related concepts from my personal perspective. A major goal of this selective review is a presentation of research findings and specific (German) research traditions that are not so much recognized internationally up to now (for an exception, see Osman 2009).

Central for this paper is an analysis of the question if CPS requires complex cognition. Therefore, I first try to define complex cognition; second, I introduce conceptually related concepts like macrocognition or operative intelligence to show the overlap of the concepts as well as their specific contributions. Third, the assessment of CPS is illustrated by two measurement approaches, Tailorshop and MicroDYN. Fourth, I point out the interaction between cognition and emotion in complex situations. Finally, some conceptual problems with the term "complex cognition" are discussed and an answer to the question in the title will be given.

Complex cognition

According to Knauff and Wolf (2010), complex cognition deals with all mental processes that are used by an individual for deriving new information out of given information, with the intention to make decisions, solve problems, and plan actions. This approach assumes an active and goal-directed information processing by human beings who are able to perceive their environment and to use their memory. The term "mental processes" is not restricted to cognitive ones but includes motivational and emotional processes at the same time.

In this understanding, complex cognition can be contrasted to simple cognition: the latter refers to the study of elementary cognitive processes like perception, memory, or learning in isolation and without asking for broader context. But are simple and complex cognition two dichotomous categories or rather two extremes of a complexity continuum? Is there a line of demarcation between them or is the complex case simply an extension of elementary processes?

An example of simple cognition is the analysis of color perception—for example, the perception of a red

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light—under conditions of reduced brightness. In contrast, complex cognition could be found in a case where a ship's captain oversaw a red warning light in the dark and is now confronted with the immediate task of accident prevention.

Whereas in the first case, a theory of color perception might help to predict the circumstances under which a red light might be overseen, in the second case, a theory of complex cognition would put the issue of an overseen red light in a broader context and might predict short-term consequences like stress, shame, and guilt processes, together with activities for error correction, and long-term consequences like increased attention to warning lights in general. The first case illustrates a cognitive process of a "pure" isolated psychic function without a meaningful action goal; the second case shows the orchestration of the whole set of cognitive functions including, for example, emotions and serves an overarching goal of action regulation like accident prevention.

Is the complex process completely understandable in terms of the addition of simple elements? Yes and no—yes, for sure, simple processes are involved in the complex situation; no, because the result of this summation follows the Gestalt principle, whereas the whole is more than the sum of its parts (von Ehrenfels 1890). In the complex situation, the result is more than the sum of perceptual, learning, and memory processes—it is an organized, hopefully well-orchestrated stream of actions serving goals of an acting individual. It is not perception or memory on its own—it is perception as part of a higher structure; it is embedded into and tuned to other psychic processes, which serve action goals. The context delivers the meaning: in our example from above, the (neutral) color red becomes a warning sign in the context of a control room, its detectability and meaning are not only given by itself but in combination with other signs and signals. The contextual embedding allows also to integrate cultural effects (Nisbett and Norenzayan 2002) and, thus, transcends a simple addition of the underlying microprocesses.

The move from the level of elementary processes to complex cognition is a shift in the hierarchy level of explanation (see for more details Rasmussen 1983): instead of talking about the detectability of red lights as a signal (level 1), one is talking about the red light as a stop sign (level 2) or even further about the stop sign as part of a broader concept of traffic regulation (level 3). The predictions (and the corresponding assessments) would be different according to these three types of "situation awareness" (Endsley 1995a, b). The line of demarcation is a matter of different levels: staying on the lowest level means simple cognition, going up the hierarchy level implies increasingly more complex cognition.

What is a complex problem?

In current theories of problem solving, a problem is conceptualized as composed of a given state, a desired goal state, and obstacles between given and goal state (Mayer 1992, p. 5). According to Anderson (2005), "any goal-directed sequence of cognitive operations" is classified as an instance of problem solving. Other authors supplement this view by emphasizing that overcoming barriers toward a desired state may involve both cognitive and behavioral means, and that these means should imply novelty and originality. Operations triggered by a problem go beyond routine action and thinking (Frensch and Funke 1995a, b).

A *complex* problem is said to occur when finding the solution demands a series of operations which can be characterized as follows (Dörner et al. 1983): Elements relevant to the solution process are large (*complexity*), highly interconnected (*connectivity*), and dynamically changing over time (*dynamics*). Neither structure nor dynamics are disclosed (*intransparency*). Finally, the goal structure is not as straight forward as suggested above: in dealing with a complex problem, a person is confronted with a number of different goal facets to be weighted and coordinated—a *polytelic situation*.

One approach to complex situations falls under the label of "Naturalistic Decision-Making" (Klein 2008; Klein et al. 1993; Lipshitz et al. 2001; Zsambok and Klein 1997). According to Zsambok (1997, p. 5), "the study of NDM asks how experienced people working as individuals or groups in dynamic, uncertain, and often fast-paced environments, identify and assess their situation, make decisions, and take actions whose consequences are meaningful to them and to the larger organization in which they operate." The four markers of this research approach—(a) complex task in real-life setting, (b) experienced decision-makers, (c) actual decision-making, and (d) situation awareness within an decision episode—are quite different to the approach frequently chosen in psychology using artificial decision situations with a focus on option selection, student subjects, and a rational standard (e.g., Kahneman et al. 1982).

Another approach falls under the label of "Complex Problem Solving" (Dörner 1980, 1996; Frensch and Funke 1995a, b; Funke 1991; Funke and Frensch 2007). According to Buchner (1995, p. 28), laboratory studies on problem solving such as chess or the famous Tower of Hanoi "… were criticized for being too simple, fully transparent, and static, whereas real-world economical, political, and technological problem situations were said to be complex, intransparent, and dynamic."

To realize such complex situations under lab conditions, Brehmer and Dörner (1993) recommended the use of computer-simulated microworlds. In the last 30 years, such microworlds have been used in numerous studies (for reviews, see Funke 1991, 1995; Funke and Frensch 2007; Osman 2009). There is a still ongoing debate if complex problem solving is a competence on its own (the related concept of operative intelligence is presented below), or if it is merely a subpart of “intelligence” (Dörner and Kreuzig 1983; Kluwe et al. 1991; Kröner et al. 2005; Rigas and Brehmer 1999; Strohschneider 1991; Süß 1996, 1999; Süß et al. 1991; Wenke and Frensch 2003; Wittmann and Hattrup 2004). I will not answer this question here but point to one central question: Is complex problem solving a good case for complex cognition? Does dealing with complex environments require a special kind of complex cognition or is CPS possible by simply adding elementary cognitive processes? This question is important, because if there does exist a second type of cognition besides simple cognition, then many questions arise—for example, about the applicability of research results from the first area to the second or about the validity of theories from one area to the other. Before giving an answer, similar and related concepts to CPS like macrocognition and operative intelligence are presented and discussed shortly.

Concepts related to complex problem solving

The previous section showed that the term “Complex Problem Solving” is used in at least three different ways (thanks to an anonymous reviewer for clarification): (1) as a paradigm to study cognition under real-life conditions (with different foci such as learning, knowledge acquisition, and decision-making), (2) as a descriptor of behavior exhibited while dealing with a certain class of problems usually presented on a computer, and (3) as an ability construct that is related to intelligence.

To clear the different understandings of CPS, it seems necessary to elaborate its connection to other related concepts. I will consider in more detail the two concepts of (a) macrocognition and (b) operative intelligence.

Macrocognition

Pietro Cacciebue and Erik Hollnagel first introduced the term “macrocognition” in 1995. They used it as a descriptor for cognitive activities in natural decision-making settings. Klein et al. (2003) used it for contrasting a research program outside the lab with the traditional lab research on microcognition that is interested in the distinctive building blocks of cognition.

To illustrate their understanding of macrocognition, Klein et al. (2003, p. 82) mention phenomena like the following: planning and problem detection using leverage points to construct options, attention management, and uncertainty management. They contrast these issues with topics from microcognition research: puzzle solving, strategies for searching problem spaces, serial versus parallel processing models, or estimating probabilities of uncertainty values.

To be clear: the main difference between both types of research is not the time axis of the focused processes, but the ill-defined conditions of the tasks and problems under consideration. And to clear another potential misunderstanding: both approaches (“types of description”) are seen as complementary to each other.

With respect to the question “inside or outside lab?”, proponents of the macrocognition approach seem to believe that these processes can only be analyzed outside “in the wild”—to quote the famous book title from Hutchins (1995). But is that really true? I do agree that many lab studies use simplified experimental paradigms for testing hypotheses about specific processes. The reason for this procedure comes from the striving for internal validity (see, e.g., Shadish et al. 2002), which guarantees correct evaluation of postulated causal relationships. But, what about “user labs” or simulators (Gray 2002)? These setups allow for much more external validity in the lab, at the same time giving control over complex conditions and processes (Brehmer and Dörner 1993). Additionally, progress in methodology allows for better data analyses in nonrandomized field situations (Shadish and Cook 2009). From my point of view, lab research is not necessarily restricted to microcognition but could be opened for macrocognition; also, macrocognition could be studied in field situations. Due to new analytic developments from our methodology, more accurate estimations of effect sizes can be used than before for analyzing such data. Also, by means of “ecological momentary assessment” new ways of data collection in real environments become possible (Hoppmann and Riediger 2009).

Operative intelligence

In an influential paper, Dörner (1986) developed the concept of “operative intelligence” as a collection of those factors that determine strategic processes like flexibility, foresight, circumspection, or systematic behavior. His main point is a claim for the concentration on thinking processes instead of on their results. To a certain extent, the theory makes a micro examination of the details of information processing, while also considering a macro approach on action theoretical concepts. By using computer-simulated scenarios, as proposed by Dörner and colleagues (Dörner 1980), large datasets are collected which should not be directly reduced to a single score (“quantificatio praecox”).

Instead, changes and stabilities of the system variables as well as changes and stabilities in participants' behavior (asking questions, making interventions) should be identified. Thus, the term "operative intelligence" comes from an interest in the details of the psychic processes underlying CPS.

To give an example: Dörner's (1986), p. 301ff) proposals for process indicators are divided in those related to questions asked by participants (only available if a thinking aloud method is used for data collection) and decisions made by them in the course of the simulation. Concerning *questions*, he differentiated between questions for states ("what is the value of … ?"), for dependencies ("what does … depend on?"), for effects ("what happens if … ?"), for components ("what do … exist of?"), for subordination ("what types of … do exist?"—specific formings of a variable), and for superordination ("what is … ?"—embedding of a specific object or event in a more abstract context). All these questions help a subject to identify the objects and their interrelations within the given domain. Concerning *decisions*, he distinguished the place of a decision from its dosage; for example, an intervention in the "Tailorshop" scenario could be made in the area of advertising, and the dosage could be the specific amount of money spent for that activity. Also, the sequence of decisions could contain interesting patterns, and the transitions from questions to decisions (and vice versa) are worthwhile analyzing.

The breadth of questions, the depth of exploration, the consistency of decisions, and the coordination of different action types are interesting indicators for describing the problem-solving behavior of subjects in complex situations. These indicators go far beyond variables that evaluate solution quality of a complex situation in a rather coarse manner. For example, analyses of transition frequencies between questions and decisions show significant differences between successful and unsuccessful problem solvers (Dörner and Wearing 1995, p. 74f).

Both in traditional and in contemporary European research on problem solving (e.g., Buchner 1995; Dörner and Wearing 1995), experiments are conducted using *complex dynamic scenarios* such as the commonly cited "Lohhausen" scenario (Dörner et al. 1983). Sternberg (1995) states that this contrasts American research on problem solving which is mainly concerned with static paradigms (e.g., Chi et al. 1982) despite some exceptions (Anzai and Simon 1979). To come back to his theory of Operational Intelligence, Dörner postulates four process components of dynamic situations, which were derived from empirical observations and are presented in the following section.

In order to successfully manage a complex system, (1) the agent has to *gather information* about the system and *integrate* this information into his model of the system. Typically, the system does not deliver any required information automatically. This forces the agent to ask specific questions or to conduct experiments that examine the way in which the variables work. This component of information retrieval and information integration is taken into account in the Multiple-Space Models by the experiment space. Goals in complex problems are often formulated only globally and unspecifically, for example, "Manage this town successfully!" Therefore, the problem solver is required to render the nonspecific goal concretely. Additionally, goals might contradict each other, which makes it necessary to balance them by working out compromises or abandoning goals. Dörner (1986) calls this (2) the ability of *goal elaboration and goal balancing*. To achieve this subgoal in turn, (3) the agent has to *plan measures and make decisions*. These measures might conflict with the agent's own system of values. This conflict can cause unpleasant emotions that affect the process of problem solving. Likewise, the agent has to cope with frustration, time pressure, and stress. In order to succeed in all this, (4) he or she needs to be capable of *self-management*.

The importance of Dörner's contribution to European research on problem solving (e.g., Bach 2003; Dörner 1986; Dörner and Schaub 1994) cannot be overstated. Nevertheless, the theory of operational intelligence offers neither a fully elaborated theory nor a measuring device, although Dörner repeatedly emphasizes the necessity of such a diagnostic device. Despite its stimulating character, the approach is not complete, resulting in a fascinating but loosely formulated theory, which still requires refinement. Because the status of a concept is sometimes best understood by pointing to the measurement approaches, the next section presents two assessment procedures from the field of CPS.

Assessment of complex problem solving

For the assessment of CPS, two different approaches exist (Buchner 1995): On the one hand, semantically rich ad-hoc simulations of complex microworlds (Brehmer and Dörner 1993), on the other hand, formally constructed artificial systems, which allow systematic variation of difficulty (Funke 2001). As an example of the first approach, the system "Tailorshop" will be presented. As an example for the second serves the "MicroDYN" approach.

Tailorshop

In 1981, the first papers about a computer-simulated scenario called "Tailorshop" (in German: "Schneiderwerkstatt") were published (Putz-Osterloh 1981; Putz-Osterloh and Lüer

1981). The scenario was originally programmed by Dietrich Dörner who started at that time a new paradigm in the psychology of thinking which later was labeled “complex problem solving” (Dörner and Reither 1978). No one could imagine at that point that “Tailorshop” would become a *Drosophila* for problem solving researchers. Numerous studies have been published (and are in the process of being published) since 1981 (Endres and Putz-Osterloh 1994; Funke 1983, 1986; Hörmann and Thomas 1989; Hussy 1991; Kersting and Süß 1995; Klocke 2004; Leutner 1988; Meyer et al. 2009; Putz-Osterloh 1981, 1983; Putz-Osterloh et al. 1990; Putz-Osterloh and Lüer 1981; Strauß 1993; Süß et al. 1991; Wittmann and Hattrup 2004).

Tailorshop is a microworld, which realizes the production conditions of a small factory. The participant takes on the role of a manager of a small shirt factory. By means of changing the input variables (number of workers, number of machines, raw material, salaries, social security contributions, maintenance, advertising, shop location, utility van, and sales price), participants can increase the satisfaction of the workers, the production conditions, the demand for shirts, and the sales figures. Figure 1 shows the connection diagram of the 24 variables.

A monthly report gives the participant all the necessary information for making decisions whose effects show up the following month. - The system is build around a set of (non)linear equations dealing with variables representing the flow of money (e.g., into investments or from sales), the production (e.g., raw material, machinery, and workforce) and the turnover factors (e.g., prices, advertisement, demand, and sales). From a system analytic point of view, the scenario is centered on two subsystems, one being responsible for production (depending on machines, workers, salaries, social security contributions, and maintenance), the other one being responsible for sales (depending on price, demand for shirts, advertising, utility vans, shop location, and restricted by the number of produced shirts).

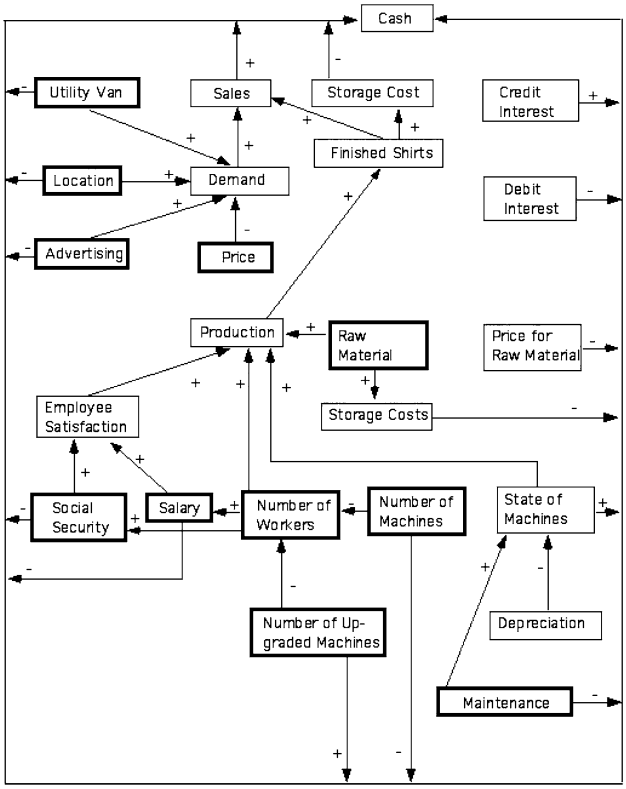

Fig. 1 Diagram of the connections within Tailorshop. Variables in *bold boxes* can be changed directly by participants (=exogenous variables), the others only indirectly (=endogenous variables)

Pseudo-random processes (i.e., for all participants, the same sequence of random numbers) determine the price for raw material, the production, and the demand in previously defined value regions. For all variables, interventions into the system become functional in the next cycle, with one exception: the demand function becomes functional in the next but one cycle instead of a direct effect.

MicroDYN

A shortcoming of CPS research (as it was introduced by Dörner in the 1970s) is its “one-item-testing” (Funke and Frensch 2007). Virtually all devices consist of one large and rather complicated scenario, the participant has to work through. At the end, either overall performance or various status and process indicators are calculated and evaluated. Thus, CPS instruments are tests which contain exactly one excessive item or at best one bundle speaking in IRT-terms (Embretson and Reise 2000) if various independent subsystems are considered as some authors do (i.e., Müller 1993). Other tests allow subjects to explore a given system over a period of time and then ask several questions about this one system. That does not make the answers any less dependent.

Bearing these limitations in mind, the question arises how dynamic problem solving could possibly be measured with psychological tests. One possible approach to individual differences might come from the formal framework of linear structural equation systems (LSE-systems), which is called the *MicroDYN approach* (see Greiff and Funke 2009). This type of items has been used considerably in experimental research as indicators for problem solving performance (Funke 2001). The basic approach, however, is now a different one as outlined below.

Items based on this approach require participants to detect causal relations and control the presented systems. It is assumed that the everyday examples mentioned earlier can be modeled by MicroDYN systems, since advanced skills in strategic planning, internal model building, and system control are crucial in the specified situations as well as those tested within the framework of MicroDYN systems. To solve the problem of one-item-testing, various completely independent systems are presented to the subjects (see below).

In summary, Greiff and Funke choose to work within the formal framework of linear structural equation systems. The MicroDYN approach may be able to overcome some of the shortcomings mentioned earlier: (a) the lack of sound theoretical frameworks calls for a different kind of framework, which MicroDYN systems offer formally (theoretical foundation). (b) MicroDYN systems are easily constructed and can be freely varied in difficulty (scalability). (c) An infinite number of independent items can be presented (unlimited item generation). (d) Many everyday activities can be described by MicroDYN items (ecological validity). Because of these features and because of its excellent psychometric properties, MicroDYN has become the first choice for the PISA 2012 consortium for the world-wide assessment of problem solving. It helps to measure the ability to identify the unknown structure of artifacts in dynamic, technology-rich environments to reach certain goals.

MicroDYN systems consist of exogenous variables, which influence endogenous variables, where only the former can be actively manipulated. Possible effects include main effects, multiple effects, multiple dependencies, autoregressive processes of first order, and side effects, which all can be freely combined. *Main effects* describe causal relations between exactly one exogenous variable and exactly one endogenous variable. If an exogenous variable is involved in more than one main effect, this is labeled a *multiple effect*. Effects on an endogenous variable influenced by more than one exogenous variable are labeled *multiple dependence*. Participants can actively control these three effects as they manipulate the values of *exogenous variables* within a given range. Effects merely incorporated within endogenous variables are called *side effects* when endogenous variables influence each other, and *autoregressive processes* when endogenous variables influence themselves (i.e., growth and shrinkage curves). Participants cannot influence these two effects directly; however, they are detectable by adequate use of strategy. Additionally, all effects may differ in path strength. Figure 2 shows examples of the presented effects.

Participants see between 8 and 12 of these items each lasting about 6 min summing to an overall testing time of approximately 1 h including instruction and trial time. The MicroDYN items are minimally but sufficiently complex and at the same time sufficient in number. Each item is processed in three stages: (1) Stage 1, *exploration phase*: participants can freely explore the system. No restrictions or goals are presented at this time. Participants can reset the system or undo their last steps. A history to trace prior steps is provided. Exploration strategies can thus be assessed. (2) Stage 2, *externalization of the mental model*: simultaneous (or subsequent) to their exploration, participants are asked to draw the connections between variables according to their assumptions. This helps to assess acquired causal knowledge. (3) Stage 3, *control phase*: participants are asked to reach given target values on the endogenous variables by entering adequate values for the exogenous variables. During this phase, the practical application of the acquired knowledge is assessed.

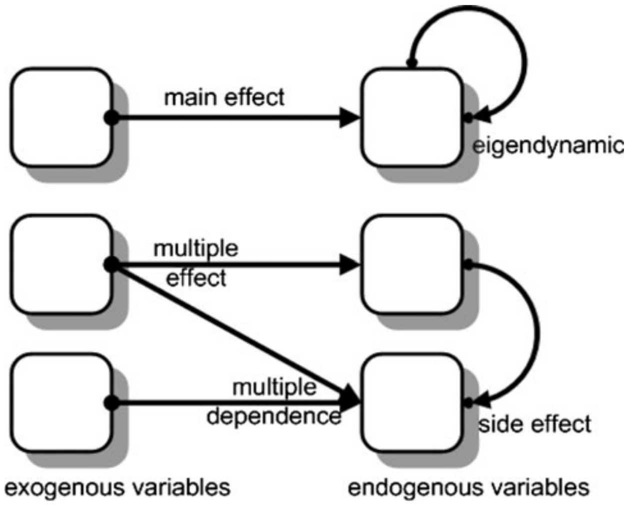

Fig. 2 Underlying structure of a MicroDYN item with all possible effects displayed. To the left are the exogenous variables, which can be manipulated directly by the participant. To the right are the endogenous variables, which have to be controlled by the subject

To summarize: two measurement approaches, Tailorshop and MicroDYN, illustrate two different understandings of CPS. Whereas Tailorshop stands for a broad interpretation of CPS but has some weak points from a psychometric point of view, MicroDYN represents the psychometric sound realization of selected but important CPS aspects. In both cases, complex cognition seems necessary, because it is not merely a sequence of simple operations, which are however part of it, but a series of very different cognitive operations like action planning, strategic development, knowledge acquisition, and evaluation processes, all of which have to be coordinated and organized around the action goals.

The connection between cognition, emotion, and motivation

One of the fascinating aspects of complex cognition is its neatless connection to emotion and motivation. From our own experience with cognitive processes, we do not differentiate between cognition, emotion, and motivation—instead, we experience an integrated course of (internal as well as external) actions with varying degrees of will and varying degrees of affection. The driving forces behind any cognition and the affective states accompanying them are more than a by-product of cognition. The founder of the modern experimental psychology of motivation, see Lewin (1935), connected the dynamics of action with his concept of personality. Today, the neuropsychology of motivational processes is better understood (see, e.g., Kalis et al. 2008), but the integration of the separate modules is still an open question. Interestingly, in studies with simple cognitive processes emotions are normally blanked out, because they do not play an important role, for example in a visual discrimination task; but in studies with complex situations, the interactions become highly visible and inevitable: if the manager of the "Tailorshop" does not succeed with her investment strategy, bad feelings emerge which in turn influence information processing. In a recent experiment with "Tailorshop", Barth and Funke (2009) showed that "nasty" environments (where participants could hardly enhance the capital and received negative feedback most of the time) increased negative and decreased positive affect. The reverse was true for nice environments where it was easy to increase capital and to receive positive feedback. Furthermore, nasty environments influenced CPS by leading to a higher information retrieval and to a better CPS performance than nice environments.

At least three different approaches—the "affect as information" approach by Schwarz (1990), the "assimilation–accommodation" approach by Fiedler (2001), and the "affect-infusion" model by Forgas (2001)—compete with each other to explain the interaction between cognitive processes and affective states. All three approaches demonstrate the necessity to connect cognitive processes with affective states. In a more elaborated phase of theory development, instead of generally speaking about positive or negative affects, it might be even possible to qualify the differential effects of different emotions (e.g., happiness or proudness; fear or anger) on information processing and vice versa. Research on complex cognition would miss its goal if this interaction would not be an integral part of the next generation's theory. Especially, the aspect of emotion regulation (Koole 2009) might become a promising area.

Cognition: simple versus complex

Is there a clear border between simple and complex cognition, and if yes, how can one determine the degree of simplicity or complexity of a cognitive process? The founder of Experimental Psychology, Wilhelm Wundt (1832–1920), believed that psychological processes could be reduced to their basic elements (and provoked strong critique for this proposition by Gestalt Psychologists)—according to that position, complexity could be computed by simply counting the required elements. But what is the basic element of a psychological process? Is it a transition between two neuronal states? The overwhelming complexity of neural processes prohibits such a simple approach.

A primitive complexity indicator could be reaction time (Welford 1980): the longer the time needed for an operation the more complex must be the underlying process. This statement assumes the sequential processing of composed elements—a proposition which is questioned by many parallel processing models of cognition (see, e.g., Bechtel and Abrahamsen 2001; Mcclelland and Rumelhart 1985). To make things even more complicated, issues for psychological research have a broad range of time. Newell (1990) differentiated between 12 time scales of human actions, coming from four different "worlds" (see Table 1).

The Biological Band is currently more intensively focused than before due to the progress of neuroscience; the Cognitive Band has been an issue for microcognition since the Cognitive Revolution; and the Rational and Social Band could be the ones for macrocognition.

But, does this differentiation on the time scale really help? What else besides time could be used for discriminating simple from complex processes? Instead of concentrating on the cognitive process, a totally different approach would be to focus on the demands posed to the cognitive system by the task. Cognitive task analysis (CTA) has a long tradition in psychology (see Crandall et al. 2006). It tries to determine the thought processes that subjects follow to perform tasks at various levels of difficulty, from novice to expert. CTA looks at a specific system from the viewpoint of the subject performing a specific task. The number and variety of required tasks could be helpful in separating simple from complex cognition.

Table 1 Newells (1990) time scales of human action in the version from Anderson (2002, p. 88)

Scale (sec)	Time units	System	World
10^7	Months		Social band
10^6	Weeks		
10^5	Days		
10^4	Hours	Task	Rational band
10^3	10 min	Task	
10^2	Minutes	Task	
10^1	10 s	Unit task	Cognitive band
10^0	1 s	Operations	
10^{-1}	100 ms	Deliberate act	
10^{-2}	10 ms	Neural circuit	Biological band
10^{-3}	1 ms	Neuron	
10^{-4}	100 µs	Organelle	

Another proposal, made by Halford et al. (1998), defines processing capacity by the relational complexity given by the number of related dimensions or sources of variation that can be processed in parallel. This approach would argue for a continuum between simple and complex processes. At the same time, it demands a definition of complexity (which is not the same as difficulty), which goes beyond the scope of this paper.

Concluding remarks

After a review of different constructs, some questions still remain open, e.g., what is the relationship between macrocognition, operative intelligence, naturalistic decision-making, and CPS? Is complex cognition the proper term or should not it be better labeled complex information processing? Concerning the relationship between the terms, it becomes obvious that they represent different research traditions; but at the same time, they all share the idea that there does exist a more complex interplay of cognitive processes than can be seen on the level of elementary processes. With respect to the question of labeling, the term “complex cognition” seems to be a good counterpart to the opposite term “simple cognition” even if it uses a broad understanding of cognition (including emotion and motivation) in the second case, which is not meant in the first one. As Moors (2009) argues, a broad sense of cognition contrasts the mental with somatic and motor responses, whereas the narrow sense contrasts cognition with motivation and emotion.

The aim of this paper was to review the concept of CPS under the perspective of complex cognition. CPS differs according to not only my view markedly from simple problem solving by introducing additional facets of the problem space like intransparency, dynamics, or polytely. At the same time, there is also a difference between simple and complex cognition. Even if this is not a clear-cut concept with a sharp border, a major difference between simple and complex cognition lies in its interaction with different psychic functions like motivation and emotion which are strongly present in the complex case but missing or at least reduced in the simple one. This interaction requires additional regulation processes, which cannot be found when studying psychic functions in isolation and out of context. So in the end, from my point of view, complex problem solving turns out to be an interesting case for complex cognition.

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References

Anderson JR (2002) Spanning seven orders of magnitude: a challenge for cognitive modeling. Cogn Sci 26:85–112

Anderson JR (2005) Cognitive psychology and its implications, 6th edn. Worth, New York

Anzai Y, Simon HA (1979) The theory of learning by doing. Psychol Rev 86:124–140

Bach J (2003) The MicroPsi agent architecture. In: Detje F, Dörner D, Schaub H (eds) Proceedings of the fifth European conference on cognitive modelling. Universitäts-Verlag Bamberg, Bamberg, pp 15–20

Barth C, Funke J (2009) Negative affective environments improve complex solving performance. Cogn Emot (in press)

Bechtel W, Abrahamsen A (2001) Connectionism and the mind: parallel processing, dynamics, and evolution in networks. Blackwell, Oxford

Brehmer B, Dörner D (1993) Experiments with computer-simulated microworlds: escaping both the narrow straits of the laboratory and the deep blue sea of the field study. Comput Hum Behav 9:171–184

Buchner A (1995) Basic topics and approaches to the study of complex problem solving. In: Frensch PA, Funke J (eds) Complex problem solving: the European perspective. Lawrence Erlbaum, Hillsdale, pp 27–63

Cacciabue PC, Hollnagel E (1995) Simulation of cognition: applications. In: Hoc JM, Cacciabue PC, Hollnagel E (eds) Expertise and technology: cognition and human-computer cooperation. Lawrence Erlbaum, Hillsdale, pp 55–73

Chi MTH, Glaser R, Rees E (1982) Expertise in problem solving. In: Sternberg RJ (ed) Advances in the psychology of human intelligence, vol 1. Lawrence Erlbaum, Hillsdale, pp 7–75

Crandall B, Klein G, Hoffman RR (2006) Working minds: a practitioner’s guide to cognitive task analysis. MIT Press, Cambridge

Dörner D (1980) On the difficulty people have in dealing with complexity. Simul Games 11:87–106

Dörner D (1986) Diagnostik der operativen Intelligenz. Diagnostica 32:290–308

Dörner D (1996) The logic of failure. Recognizing and avoiding error in complex situations. Addison-Wesley, Reading

Dörner D, Kreuzig HW (1983) Problemlösefähigkeit und Intelligenz. Psychologische Rundschau 34:185–192

Dörner D, Reither F (1978) Über das Problemlösen in sehr komplexen Realitätsbereichen. Zeitschrift für Experimentelle und Angewandte Psychologie 25:527–551

Dörner D, Schaub H (1994) Errors in planning and decision-making and the nature of human information processing. Appl Psychol Int Rev 43:433–453

Dörner D, Wearing AJ (1995) Complex problem solving: toward a (computersimulated) theory. In: Frensch PA, Funke J (eds) Complex problem solving: the European perspective. Lawrence Erlbaum, Hillsdale, pp 65–99

Dörner D, Kreuzig HW, Reither F et al (1983) Lohhausen. Vom Umgang mit Unbestimmtheit und Komplexität, Hans Huber

Embretson SE, Reise SP (2000) Item response theory for psychologists. Lawrence Erlbaum, Mahwah

Endres J, Putz-Osterloh W (1994) Komplexes Problemlösen in Kleingruppen: Effekte des Vorwissens, der Gruppenstruktur und der Gruppeninteraktion. Zeitschrift für Sozialpsychologie 25:54–70

Endsley MR (1995a) Measurement of situation awareness in dynamic systems. Hum Factors 37:65–84

Endsley MR (1995b) Towards a theory of situation awareness in dynamic systems. Hum Factors 37:32–64

Fiedler K (2001) Affective states trigger processes of assimilation and accomodation. In: Martin LL, Clore GL (eds) Theories of mood and cognition: a user's guidebook. Lawrence Erlbaum, Mahwah, pp 85–98

Forgas JP (2001) The affect infusion model (AIM): an integrative theory of mood effects on cognition and judgments. In: Martin LL, Clore GL (eds) Theories of mood and cognition. Erlbaum, Mahwah, pp 99–134

Frensch PA, Funke J (1995a) Definitions, traditions, and a general framework for understanding complex problem solving. In: Frensch PA, Funke J (eds) Complex problem solving: the European perspective. Lawrence Erlbaum, Hillsdale, pp 3–25

Frensch PA, Funke J (eds) (1995b) Complex problem solving: the European perspective. Lawrence Erlbaum, Hillsdale

Funke J (1983) Einige Bemerkungen zu Problemen der Problemlöseforschung oder: Ist Testintelligenz doch ein Prädiktor? Diagnostica 29:283–302

Funke J (1986) Komplexes Problemlösen - Bestandsaufnahme und Perspektiven. Springer, Heidelberg

Funke J (1991) Solving complex problems: exploration and control of complex systems. In: Sternberg RJ, Frensch PA (eds) Complex problem solving: principles and mechanisms. Lawrence Erlbaum, Hillsdale, pp 185–222

Funke J (1995) Experimental research on complex problem solving. In: Frensch PA, Funke J (eds) Complex problem solving: the European perspective. Lawrence Erlbaum, Hillsdale, pp 243–268

Funke J (2001) Dynamic systems as tools for analysing human judgement. Think Reason 7:69–89

Funke J, Frensch PA (2007) Complex problem solving: the European perspective—10 years after. In: Jonassen DH (ed) Learning to solve complex scientific problems. Lawrence Erlbaum, New York, pp 25–47

Gray WD (2002) Simulated task environments: the role of high-fidelity simulations, scaled worlds, synthetic environments, and laboratory tasks in basic and applied cognitive research. Cogn Sci Q 2:205–227

Greiff S, Funke J (2009) Measuring complex problem solving: the MicroDYN approach. In: Scheuermann F (ed) The Transition to computer-based assessment—lessons learned from large-scale surveys and implications for testing. Office for Official Publications of the European Communities, Luxembourg

Halford GS, Wilson WH, Phillips S (1998) Processing capacity defined by relational complexity: implications for comparative, developmental, and cognitive psychology. Behav Brain Sci 21:803–865

Hoppmann CA, Riediger M (2009) Ambulatory assessment in lifespan psychology: An overview of current status and new trends. European Psychologist (in press)

Hörmann H-J, Thomas M (1989) Zum Zusammenhang zwischen Intelligenz und komplexem Problemlösen. Sprache & Kognition 8:23–31

Hussy W (1991) Komplexes Problemlösen und Verarbeitungskapazität. Sprache & Kognition 10:208–220

Hutchins E (1995) Cognition in the wild. MIT Press, Cambridge

Kahneman D, Slovic P, Tversky A (1982) Judgement under uncertainty. Heuristics and biases. Cambridge University Press, Cambridge

Kalis A, Mojzisch A, Schweizer TS et al (2008) Weakness of will, akrasia, and the neuropsychiatry of decision-making: an interdisciplinary perspective. Cogn Affect Behav Neurosci 8:402–417

Kersting M, Süß H-M (1995) Kontentvalide Wissensdiagnostik und Problemlösen: Zur Entwicklung, testtheoretischen Begründung und empirischen Bewährung eines problemspezifischen Diagnoseverfahrens. Zeitschrift für Pädagogische Psychologie 9:83–93

Klein G (2008) Naturalistic decision making. Hum Factors 50:456–460

Klein G, Orasanu J, Calderwood R et al (eds) (1993) Decision making in action: models and methods. Ablex, Norwood

Klein G, Ross KG, Moon BM et al (2003) Macrocognition. IEEE Intell Syst 18:81–85

Klocke U (2004) Folgen von Machtausübung und Einflussnahme für Wissenszuwachs und Effektivität in Kleingruppen. In: Mathematisch-Naturwissenschaftlichen Fakultät II. Humboldt-Universität zu Berlin, Berlin

Kluwe RH, Misiak C, Haider H (1991) The control of complex systems and performance in intelligence tests. In: Rowe H (ed) Intelligence: reconceptualization and measurement. Lawrence Erlbaum, Hillsdale, pp 227–244

Knauff M, Wolf AG (2010) Editorial. Complex Cognition this volume

Koole SL (2009) The psychology of emotion regulation: an integrative review. Cogn Emot 23:4–41

Kröner S, Plass JL, Leutner D (2005) Intelligence assessment with computer simulations. Intelligence 33:347–368

Leutner D (1988) Computersimulierte dynamische Systeme: Wissenserwerb unter verschiedenen Lehrmethoden und Sozialformen des Unterrichts. Zeitschrift für Entwicklungspsychologie und Pädagogische Psychologie 20:338–355

Lewin K (1935) A dynamic theory of personality (selected papers). McGraw-Hill, New York

Lipshitz R, Klein G, Orasanu J et al (2001) Taking stock of naturalistic decision making. J Behav Decis Mak 14:331–352

Mayer RE (1992) Thinking, problem solving, cognition, 2nd edn. W. H. Freeman, New York

McClelland JL, Rumelhart DE (1985) Distributed memory and the representation of general and specific information. J Exp Psychol Gen 114:159–188

Meyer B, Grütter J, Oertig M et al (2009) Women's underperformance in complex problem solving: stereotype threat in microworld performance. Eur J Soc Psychol (under review)

Moors A (2009) Theories of emotion causation: a review. Cogn Emot 23:625–662

Müller H (1993) Komplexes Problemlösen: Reliabilität und Wissen. Holos, Bonn

Newell A (1990) Unified theories of cognition. Harvard University Press, Cambridge

Nisbett RE, Norenzayan A (2002) Culture and cognition. In: Pashler H, Medin D (eds) Steven's handbook of experimental psychology. Third edition. Vol. 2: memory and cognitive processes. John Wiley, New York, pp 561–597

Osman M (2009) Controlling uncertainty: a review of human behavior in complex dynamic environments. Psychol Bull (in press)

Putz-Osterloh W (1981) Über die Beziehung zwischen Testintelligenz und Problemlöseerfolg. Zeitschrift für Psychologie 189:79–100

Putz-Osterloh W (1983) Über Determinanten komplexer Problemlöseleistungen und Möglichkeiten zu ihrer Erfassung. Sprache & Kognition 2:100–116

Putz-Osterloh W, Lüer G (1981) Über die Vorhersagbarkeit komplexer Problemlöseleistungen durch Ergebnisse in einem Intelligenztest. Zeitschrift für Experimentelle und Angewandte Psychologie 28:309–334

Putz-Osterloh W, Bott B, Köster K (1990) Modes of learning in problem solving—are they transferable to tutorial systems? Comput Hum Behav 6:83–96

Rasmussen J (1983) Skills, rules, knowledge: signals, signs, and symbols, and other distinctions in human performance models. IEEE Trans Syst Man Cybern SMC 13:257–266

Rigas G, Brehmer B (1999) Mental processes in intelligence tests and dynamic decision making tasks. In: Juslin P, Montgomery H (eds) Judgement and decision making: Neo-Brunswikean and process-tracing approaches. Lawrence Erlbaum, Hillsdale, pp 45–65

Schwarz N (1990) Feelings as information: informational and motivational functions of affective states. In: Higgins ET, Sorrentino RM (eds) Handbook of motivation and cognition. Guilford Press, New York, pp 527–561

Shadish WR, Cook TD (2009) The renaissance of field experimentation in evaluating interventions. Annu Rev Psychol 60:607–629

Shadish WR, Cook TD, Campbell DT (2002) Experimental and quasi-experimental designs for generalized causal inference. Houghton Mifflin, Boston

Sternberg RJ (1995) Expertise in complex problem solving: a comparison of alternative conceptions. In: Frensch PA, Funke J (eds) Complex problem solving: the European perspective. Lawrence Erlbaum, Hillsdale, pp 295–321

Strauß B (1993) Konfundierungen beim Komplexen Problemlösen. Zum Einfluß des Anteils der richtigen Lösungen (ArL) auf das Problemlöseverhalten in komplexen Situationen. Holos, Bonn

Strohschneider S (1991) Problemlösen und Intelligenz: Über die Effekte der Konkretisierung komplexer Probleme. Diagnostica 37:353–371

Süß H-M (1996) Intelligenz. Wissen und Problemlösen, Hogrefe, Göttingen

Süß H-M (1999) Intelligenz und komplexes Problemlösen—Perspektiven für eine Kooperation zwischen differentiell-psychometrischer und kognitionspsychologischer Forschung. Psychologische Rundschau 50:220–228

Süß H-M, Kersting M, Oberauer K (1991) Intelligenz und Wissen als Prädiktoren für Leistungen bei computersimulierten komplexen Problemen. Diagnostica 37:334–352

von Ehrenfels C (1890) Über Gestaltqualitäten. Vierteljahrsschrift für Wissenschaftliche Philosophie 14:249–292

Welford AT (ed) (1980) Reaction times. Academic Press, New York

Wenke D, Frensch PA (2003) Is success or failure at solving complex problems related to intellectual ability? In: Davidson JE, Sternberg RJ (eds) The psychology of problem solving. Cambridge University Press, Cambridge, pp 87–126

Wittmann WW, Hattrup K (2004) The relationship between performance in dynamic systems and intelligence. Syst Res Behav Sci 21:393–409

Zsambok CE (1997) Naturalistic decision making: where are we now? In: Zsambok CE, Klein GA (eds) Naturalistic decision making. Lawrence Erlbaum, Mahwah, pp 3–16

Zsambok CE, Klein GA (eds) (1997) Naturalistic decision making. Lawrence Erlbaum, Mahwah