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Research Article

Dealing With Stress and Complex Problem Solving

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Abstract

The ability to solve complex problems ('CPS performance') enables persons to achieve goals under complex conditions, which are characterized by their complexity, connectivity, dynamics, intransparency, and polytely. This study was designed to investigate the following hypothesis: The way to deal with stress is related to CPS performance. Participants in the present study (N=126) at first provided their demographical data, then subsequently completed a detailed test measuring stress processing strategies and finally were given a mission in a complex scenario implemented in Cities: Skylines, a microworld scenario. Results show that people who tend to make many thoughts after stress situations and people who question (or even self-incriminate) themselves (internal attribution) in stress situations have better chances to succeed in complex problem solving tasks. In men, we found significant and positive correlations between situation control, reaction control, as well as positive self-instruction and successful problem solving, whereas we did not find any significant positive correlations in women. For this group, we only found significant negative correlations, namely that trivializing and playing down stress are negatively correlated with successful problem solving.

Keywords: Cps; Decision Making; Stress; Internal and External Stress Processing

Theoretical Background

Living in a world of growing possibilities, we are continuously surrounded by challenging tasks and problems. Apparently simple sequences of decisions, like finding a destination in an unknown city, turn out to be highly complex if examined in detail. Such situations have certain characteristics and require specific cognitive abilities similar to those inherent in much more challenging situations, like managing a company, or avoiding the next world war. These characteristics and cognitive processes are subjects of problem-solving research. Concluding from such examples, findings from this research area are highly relevant for a wide range of situations in everyday life. One particularly young topic in this field of research investigates individual differences in how people deal with especially complex types of problems. What drives psychological research on complex problem solving (CPS), for instance, are questions about the reason for inter- and intraindividual differences in performance when trying to achieve given goals, especially under rather complex conditions; about the nature of those cognitive and emotional processes that influence our decisions when we find ourselves in completely new situations; or about strategies that we consciously or unconsciously use to be able to solve even the most challenging problems that we know in the world; etc. But before giving an overview of the construct of interest, some key terms from general research on problem solving ought to be clarified: A problem exists when a person does not know how to achieve a current goal. Problem solving therefore corresponds to the cognitive processes that eliminate the barrier between the actual state and the desired goal state [1]. Concluding from its definition, problem solving is an extremely important set of skills. For this reason, related research gains more and more popularity and even large-scale assessments like the Programme for International Student Assessment [2] implemented both simple- and complex-problem-solving competencies in their assessments. Whereas simple problems are well-defined (by a clear set of possible solutions) and have a correct solution, complex problems, on the other hand, are ill-defined and have no clear solution. More specifically, as formulated by Funke [3-6], complex problem situations have five characteristic features.

Complexity

Complexity means that a large quantity of variables is involved in a problem, and therefore have to be considered to be able to solve it. Confronted with this amount of potentially relevant or irrelevant variables, it is necessary to reduce it effectively to find which variables may be important.

Connectivity

Connectivity means that between a large number of variables there also exist many connections. They influence each other in different, not necessarily linear ways. A problem that includes many variables, of which every single one is related to some other variables in different ways, for instance, has a much higher connectivity than a similar problem with the same number of variables, of which each is just influencing one other variable. In the latter problem, the structure of causal relationships would be understood much more easily. In this way, the level of connectivity relates to the (in)transparency of problems. Having to understand a large number of interrelations complicates the process of modeling the problem structure.

Dynamics

Dynamics refer to the attribute of complex problem situations to change over time, both depending on a subject´s actions, and autonomously. In addition to the large number of interrelated variables, time is a relevant factor for learning processes and for actions to show effects. But it can also lead to unexpected consequences of one´s own actions if dynamic aspects are not considered beforehand. As a special case of dynamics, complex problems can also include eigendynamics, autonomous changes that are not influenced by the subject´s interactions with variables. This feature could be induced by variables influencing each other, or simply changing over time in a nonlinear fashion. Eigendynamics, by definition, add an invisible component to the structure of interrelated variables, thereby frustrating the ability to simply draw conclusions from observed changes in the variables. As a consequence, eigendynamics influence both how much knowledge can be gathered about the affected variables in a complex problem situation, and to what extent these variables can be controlled by someone´s actions in the respective situation.

Intransparency

Intransparency refers both to the involved variables and to goals as well: All the characteristics described above influence the (in)transparency of variables and their relationships. Additionally, goals in complex problem situations are not clearly defined (e.g., “find a birthday present for X”). As in transparencies have to be eliminated before being able to draw conclusions about possible ways to achieve goals, the ability to effectively gather information is essential.

Polytely

Polytely is the existence of many goals, which may even be conflicting. For instance, it applies to situations in which the main goal can only be achieved after achieving many smaller goals. Under complex and in transparent conditions, these goals would be conflicting in case of an unexpected negative event. This event would interrupt the process of chasing current goals and cause the subject to first care about unexpected goals (i.e., problems). Hence, polytely requires the ability to evaluate and to set priorities. A practical example for these characteristics is the interaction with a new mobile phone: There is an apparently endless number of menus, symbols, functions etc. (complexity); variables are highly interconnected (e.g., changing the system language will affect all menu titles, but not their symbols); the system will change dynamically through actions of the user, but also autonomously (e.g., automatically updating weather reports); and at least parts of the underlying causal structure are not transparent to the user (e.g., when it shuts down without any apparent reason). Just as in this example, research on CPS has shown that, when confronted with a complex and dynamic system, one needs to interact with it to learn about its underlying causal structure, which then is necessary for being able to control it.

Measurement Approaches

Approaches to measuring CPS performance can be divided into rather process-oriented Microworlds and psychometric approaches, like MicroDYN [7].

Microworlds

Research on Complex Problem Solving started with Dietrich Dörner [8], who criticised measurements of general intelligence for using rather simple tasks, as compared to the complexity of real-life problems. He proposed the assessment of intelligent behavior in computer-based scenarios that are specifically designed to simulate the characteristics of complex problems in everyday life [9]. Dörner and his colleagues used so-called Microworlds and [10] to investigate how subjects acted under complex, dynamic, and intransparent conditions when given a goal that could only be achieved by controlling parts of the system´s structure. In their most popular study, participants were given the instruction to manage a small German city called Lohhausen, in order to provide the best possible conditions for the city and its population [11]. As this microworld included more than 2.000 variables, high complexity was assured, also requiring a high-quality operationalization of CPS. But as performance in Lohhausen was operationalized as a factor assembled from 6 main criteria, of which some were subjective evaluations, its general validity was a critical issue. One of these criteria even was the participant´s own rating of his or her performance. This definition of a parameter for CPS performance makes the interpretation of results very questionable. The reason for this definition could have been that the goal description - to care for a high well-being of the population - was too unclear and open to subjective interpretation [12]. More recently, some authors [13-14] have shown that CPS performance can also be assessed psychometrically valid in complex microworlds.

MicroDYN

Operationalizations within the MicroDYN approach consist of a few linear equations that describe the underlying causal structure between input and output variables. These variables are often represented in numerical values and slide controls. The components can be implemented in different semantic cover stories (e.g., a chemistry laboratory with different substances that can be mixed in different proportions). Within each MicroDYN task, the complex-problem-solving process is split into two phases: (a) the representation phase, in which the participant explores the system (by interacting with it) and is then asked to enter the supposed causal structure into a diagram, followed by (b) the solution phase, in which he or she receives the correct underlying causal structure and has to control the input variables accordingly to reach given goal values in the output variables. MicroDYN tasks are economic in construction and administration (each task is completed in 5 minutes), their measurements are reliable, and tasks can be constructed differing in their semantic cover story and/or their causal structure [15]. For instance, and found 5% incremental validity of CPS performance (in MicroDYN tasks) beyond reasoning in predicting school grades. Because of this attribute, they are especially intended for the use as an alternative to common measures of intelligence [16]. However, some authors strongly argued against the MicroDYN approach to measure CPS performance [17,18]. For instance, Funke (2014) [19] criticised the validity of MicroDYN tasks for eliciting other cognitive processes than more complex and naturalistic systems, such as microworlds.

It was argued that MicroDYN operationalizations of CPS are lacking

a) complexity, as there are only a few variables involved in each task

b) connectivity, as there are also few, mostly linear interrelations between variables

c) dynamics, as there is a restricted number of interactions that participants have with a system during the short exploration phase, thus not leaving much time for eigendynamics or non-linear (e.g., exponential) influences to show observable effects on the output variables

d) intransparency, as the underlying structure is revealed during the solution phase, when the system has to be controlled towards specific output values; and

e) polytely, as MicroDYN tasks may indeed impose more than one goal on participants, but they are neither conflicting nor do they form a sequence of smaller goals required for the achievement of the main goal(s) [20].

Stress processing

Stress is recognised as an important issue in basic and clinical neuroscience research. There are a lot of strategies to deal with stress, some based on avoidance and denial, and some based on e.g. trivialisation or deflecting a possible own fault. According to Richard Lazarus, stress is a two-way process; it involves the production of stressors by the environment, and the response of an individual subjected to these stressors. His conception regarding stress led to the theory of cognitive appraisal. He stated that cognitive appraisal occurs when a person considers two major factors that majorly contribute in his response to stress. These two factors include the threatening tendency of the stress to the individual, and the assessment of resources required to minimize, tolerate or eradicate the stressor and the stress it produces. In general, cognitive appraisal is divided into two types or stages: primary and secondary appraisal. In the stage of primary appraisal, an individual tends to ask questions like, "*What does this stressor and/ or situation mean?*", and, "How can it influence me?" According to psychologists, the three typical answers to these questions are: "this is not important", "this is good" or "this is stressful". When the answer is "this is stressful" then secondary appraisals appear and the person has to deal with the stressor. Uttering statements like, *"I can do it if I do my best"*, *"I will try whether my chances of success are high or not"*, and *"If this way fails, I can always try another method"* indicates positive secondary appraisal. In contrast to these, statements like, *"I can't do it; I know I will fail"*, *"I will not do it because no one believes I can"* and, *"I won't try because my chances are low"* indicate negative secondary appraisal. This study analyzes, which secondary appraisals correlate significantly with successful problem solving.

Hypotheses and aims of the study

It was hypothesized that the way to deal with stress was expected to be related to CPS performance.

Methods

Participants

The present study was conducted at the University of Salzburg and the College of Education in Salzburg, Austria.

The sample consisted of N=192 participants (47,7% male). The mean age of participants was M=24.29 years (SD=2.14).

Material

To test the hypotheses mentioned in the section above, the following material was used.

SVF120

To examine how participants deal with stress, they conducted the SVF120 [21]. Containing 120 items in 20 scales to measure stress processing in stressful situations. We recorded traits like playing down stress situations, trivializing stress, distraction, compensatory satisfaction, self-affirmation, denial, social isolation, making thoughts about what happened, aggression and relaxing, matching to Lazarus' theory of secondary appraisal.

Cities: Skylines (CSL)

Cities: Skylines [22] is a computer-based simulation game about building and managing a city. As declared in the user manual, it "offers endless sandbox play in a city that keeps offering new areas, resources, and technologies to explore, continually presenting the player with new challenges to overcome" [22]. This computer game was used as a microworld, as it meets characteristic features of complex problem situations and, respectively Brehmer and Dörners [23] and criteria for microworlds, as they are part of Funke´s specification. These attributes enable the assessment of CPS performance in participants that are interacting with the microworld. How these characteristics apply to Cities: Skylines can be illustrated using the following examples (see Figure 1 [24,25]).

Complexity

The simulation consists of endless structures (like zones, natural resources, streets, buildings, water and electricity infrastructures, etc.), possibilities (like taxes, budgets, loans, traffic control, health, safety and education policies, etc.), and parameters (like number of inhabitants, population happiness, pollution, criminality, etc.). For instance, when buying a wind turbine, the player can consider its price, the weekly budget, its noise pollution, production of electricity dependent of its placement, its requirement for a connection to the cities´ electric system, etc.

Connectivity

All changes have consequences in the short- and long-term and the player can estimate some of them from info boxes or conclude from related knowledge in real-life. Nevertheless, all such assumptions have to be tested to find causal influences. Connectivity is met as variables in the simulation are highly interrelated, meaning that there is not only a vast number of factors in the system (complexity), but that also each of them is connected to some other factors (Figure 1), influencing each other in different ways. For instance, wind turbines should not be placed near residential zones because their noise pollution upsets the people living in the neighborhood, lowering their happiness and the ground value of their houses.

Dynamics

The main aspects of autonomous and time-dependent variables are the population´s needs and complaints. For instance, zoning demands change autonomously over time (i.e. "eigendynamics"), while also depending partly on the players´ actions. With the city population and area extending over time, the water and electricity infrastructure, number of schools, hospitals, cemeteries etc. that cover the needs of the population in one moment won´t be sufficient at a later moment. In addition, every building or street has a specific lifespan (depending on its use) until it is abandoned and needs to be replaced.

Intransparency

Intransparency is not an essential part of Cities: Skylines but is mainly induced by its complexity and connectivity. The vast number of variables and interrelations between them makes the active exploration inevitable. But there are also really intransparent features, e.g., irregular death waves independent of the players´ actions, or increases in the frequency of fires in the city after the player builds the first fire department (contrary to expectations).

Polytely

The player is required to constantly check up on demands and complaints of the population because both cannot easily be predicted. With the mission for participants in the present study being to increase the cities´ population (see next section), many influences on the number of inhabitants have to be considered at the same time (Figure 1). Under these conditions, the main goal can only be achieved after many smaller goals (e.g., distributing bus stations strategically for students and workers) are achieved. In case of unexpected problems (e.g., a disease spread from water pollution), the current goals are often conflicting and therefore have to be evaluated quickly to adequately set priorities. Such an unexpected problem situation would require the player to stop chasing his/her current goals, to analyse and evaluate potential causes and consequences of the new problem, and either apply already known strategies or newly explore practical solutions. How these characteristics of the simulation were partially controlled by using a standardized scenario and a specific instruction will be addressed in the following sections.

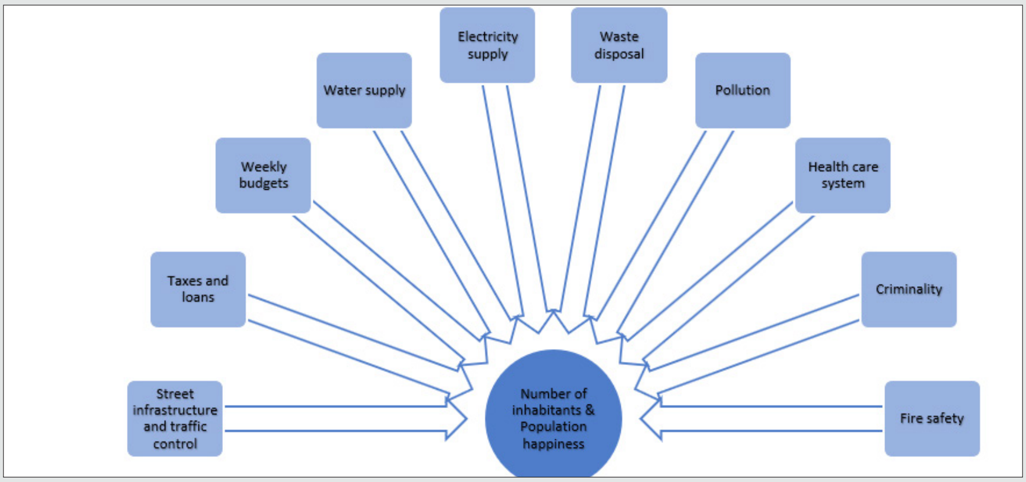

Figure 1: Exemplary model of some (not all) factors that influence the number of inhabitants and the general happiness of the population in Cities: Skylines (CSL). The number of related variables illustrates the complexity, connectivity and polytely in the simulated environment.

Conditions in the Study

Similar to the popular microworld Lohhausen [26], players in Cities: Skylines essentially take the role of the cities´ mayor, together with all its power and responsibility. For the present study, each participant was given the same scenario with the following preconditions: a small, fully functioning city with a population of 2.600 inhabitants, 50.000 units of in-game money and the general happiness of the population being 90%.

They were given the following mission

"Your mission is to increase the cities´ population to 5.000 inhabitants. Conditions: The inhabitants should not be unhappy, and your bank account should not decrease to 0. Advice: Often, priorities have to be set, so don´t forget the mission!" (Translated by the author). The mission was accomplished if the population reached 5.000 inhabitants, while having maintained an average happiness level of at least 75%. On the contrary, the mission was failed if (a) the cities´ population size decreased to 1.000 inhabitants, (b) the bank account reached the value 0, or (c) the maximum playing time of 120 minutes had passed.

Parameter for cps in the microworld

Derived from the task to increase the cities´ population a parameter for complex-problem-solving performance was computed as follows:

$$CPS = \frac{\sum \textit{population differences between time points}}{\textit{number of time points} - 1} \times \frac{\textit{population maximum}}{\textit{population goal}}$$

The CPS parameter was therefore defined as the averaged population gain over time, weighted by the proportion of the goal (5.000 inhabitants) that was completed. Cities: Skylines contains info statistics and diagrams in which players can observe the development of important variables in their city over time. For every participant in the present study, the relevant variable ("population") was exported from CSL using the Mod CSLMoreGraphs which was downloaded from Steam Workshops [27].

Instruction

Participants were instructed on how to navigate through the simulation. Contrary to some other operationalizations of CPS, they were also given a short demonstration on a list of basic functions in the game: placement of streets, buildings, water pumps, and wind turbines; zoning (placement of Residential, Commercial and Industrial/Office Zones) and the bulldozer mode; structural overview of electricity, water pipes, and garbage disposals; finding info statistics to see what the population needs. For measurement purposes, they were instructed not to change the default time settings (as this would produce bias in the measurement points). Without such a profound instruction, gaming-inexperienced participants, by nature, would have performed much worse than gaming-experienced ones, considering that the latter group would probably already be familiar with the basic structure of similar computer games. Their domain knowledge unfairly would have improved their performance, reducing the influence of the microworld´s characteristics on the problem-solving variable. Hence, the instruction was intended to increase fairness despite different preconditions.

Short Questionnaire

Participants were asked to provide demographical information, i.e., their age, gender, nationality, and level of education. They also had to rate their amount of prior experience with city-building simulation games on a 4-point scale ranging from "none" to "very much". Assessing this information was important to investigate if there were effects of prior knowledge on problem-solving performance in the mission, i.e., gaming-experienced participants being able to explore the microworld faster than non-experienced participants. This rating served as a definition of domain-knowledge in the sense of the Elshout-Raaheim-Hypothesis [28,29]. On the same questionnaire was a list of 20 symbols from Cities: Skylines, together with their meanings (e.g., "no electricity"), which participants could consult during the mission. Finally, the difficulty of the mission had to be rated on a 5-point scale ranging from 1 (very easy) to 5 (very difficult). The experimenter also noted on each questionnaire (a) if the respective participant could complete the mission (Success, Failure, or Participant Breakup), and (b) on which time of the day the testing session was taken (morning, afternoon, or evening).

Procedure

The testing procedure took place in a computer laboratory of the Department of Psychology at the University of Salzburg, Austria. Participants were invited individually in groups of up to 8 subjects per testing session. Desks and PCs in this computer lab were arranged in a way that did not allow participants to see each other while completing the tasks. As can be seen in Figure 2, at first, participants were given a short information about the procedure of the study and had to sign an informed consent form. Then they completed the Short Questionnaire described above (approximately 2 minutes). Thereafter, they completed the Stress Processing Test (approximately 15 minutes). The participants received a leaflet explaining the mission in Cities: Skylines and were given a demonstration of the in-game navigation, as well as a verbal instruction on a list of basic functions in the game (approximately 7 minutes). Then, each participant was given a laptop to play the mission on. If participants had questions regarding the game, they were only answered if the content was part of the instruction. Approximately every 20 minutes, the experimenter checked up on their cities´ status. Apart from that, they were left alone to explore the microworld until they either succeeded, failed, or decided to break up. In any case, in the end, participants answered the last question on the Short Questionnaire (concerning the difficulty of the mission) and were then thanked and dismissed. This procedure was completed in a single testing session with a total duration of approximately 90 to 150 minutes, depending on the time spent on the mission.

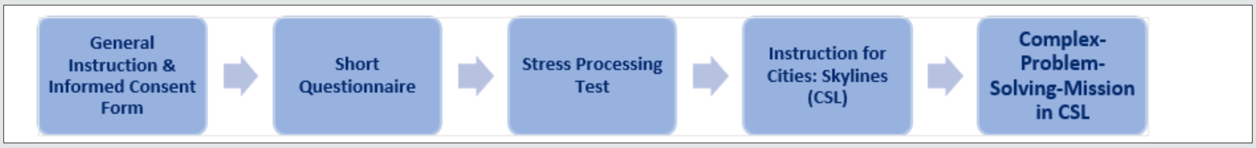

Figure 2: Procedure of the study.

Results

Descriptive analyses

Asked about their prior experience with city-building simulation games, 28,6% of the participants reported to have "none", 57,1% reported having had "some" experience, 7,1% reported "much" experience and also 7,1% reported experience "very much". 50% of participants rated the game as "easy" or "rather easy", 37,5% rated it as "not easy but also not difficult" and 12,6% said, that the game was "difficult" or "very difficult".

Results

Correlating problem solving ability and stress processing, we found a significant correlation between "thoughts about stress" ($r = .346$, $p < .01$) and problem-solving ability as well as between self-affirmation and successful problem solving ($r = .245$, $p < .05$). The more people think about what the stressor was and how they reacted, the better the problem-solving performance and the more people attribute stress as internal problem, the better the achievement in the problem-solving task. Also, when controlling for prior experience, correlations are highly significant. When checking correlations for males and females separately, we found a positive and significant correlation between successful problem solving and self-affirmation ($r = .395$, $p < .01$), situation control ($r = .353$, $p < .01$), reaction control ($r = .247$, $p < .05$), positive self-instruction ($r = .298$, $p < .05$) in men and a negative correlation between CPS and playing down stress ($r = -.279$, $p < .05$) and trivializing stress ($r = -.244$, $p < .05$) in women.

Further analyzes (post hoc)

We also checked correlations between capacity (from another questionnaire, the BIP which tests for job relevant personal traits) and CPS and found a positive and significant correlation ($r = .300$, $p < .05$). High load capacity is significant and positively related to successful problem solving. Capacity and "thoughts about stress" as well as between self-affirmation were not significantly correlated ($p > .05$).

Discussion

The present study examines influences of stress processing strategies on CPS performance. The positive correlation between "thoughts about stress" and successful problem solving can be traced back to the fact that people who think about reasons of stress tend to deal with potential problems at an early stage and think of potential problems which might appear as they attribute stress internally.

Conclusion

In the microworld, they might plan better than subjects who think less about stress. Self-affirmation is a trait that expresses to which extent people question and self-affect themselves, i.e., by attributing events internally instead of externally. A possible constellation would be that they change decisions in the game, as they understand that the reason for not being successful in the game is not external but only internal. External attribution obviously leads to more unelected decisions whereas internal attribution is a trait which has a positive effect on successful problem solving. Controlling the situation (following external attribution) and positive self-instruction are rather male attributes [30], which could be seen as the reason for positive correlations only in men, as they display a broader range of scores on this scale.

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