What Makes a Problem Complex?

Factors Determining Difficulty in Dynamic Situations and Implications for Diagnosing Complex Problem Solving Competence

Samuel Greiff and Joachim Funke

University of Heidelberg, Germany, samuel.greiff@psychologie.uni-heidelberg.de

Complex problem solving within dynamic systems has been an area of major interest in experimental research over the last decades. Comparatively little research has been conducted about complex problem solving in the context of individual differences. However, embedded in the recent development of large-scale assessments in educational settings, cross-curricular competencies such as complex problem solving have been discovered as valuable aspects of school achievement. Applied implications of complex problem solving involve situations comprising of the following characteristics: different variables influence one or more outcomes, the underlying system is not static and exhaustive information and evaluation of the situation may not be obtained. Many everyday activities can be described within this formal framework ranging from medical emergencies over evaluating one's monthly expenses to handling ticket machines at train stations. Despite the awakening interest in individual differences, there is still a substantial lack of well-scrutinised testing devices. Additionally, little agreement on how to measure complex problem solving on an individual level has been reached and sound theoretical foundations to be used as starting points are still rare.

We assume that individual differences can possibly be detected within the formal framework of linear structural equation systems (LSE-systems). Items based on this approach require participants to detect causal relations and control the presented systems. We suppose that the everyday examples mentioned above can be modelled by LSE-systems since advanced skills in strategic planning, internal model building and system control are crucial in the specified situations as well as tested within the framework of LSE-Systems.

LSE-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 lateral effects, which all can be freely combined. *Main effects* describe causal relations from exactly one exogenous variable to exactly one endogenous variable. If an exogenous variable is involved in more than one main effect, this is labelled a *multiple effect*. Effects on an endogenous variable influenced by more than one exogenous variable are labelled a *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 *lateral 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. Yet, attributes determining the difficulty of LSE-systems must be thoroughly investigated.

This paper is intended as a contribution to the question which factors influence the difficulty of LSE-systems. Based on a detailed task analysis, the following factors are identified as potentially significant: (1) quality of effects, (2) quantity of effects, (3) strength of paths, (4) number of variables, (5) variable dispersion, (6) effect configuration, as well as (7) initial and target value.

Quality of effects describes the different kinds of causal relations mentioned above and is presumably one of the major aspects determining difficulty with main effects being rather easy and autoregressive processes being rather hard to detect. *Quantity of effects* specifies the number of effects implemented regardless of their quality whereas many effects supposedly cause an increase in difficulty. *Strength of paths* specifies how large and thus how detectable a causal relation is. However, relative path values are more important than the absolute path values. *Number of variables* describes the mere number of exogenous and endogenous variables involved with more variables constituting more difficult items. *Variable dispersion* specifies how closely a given number of effects is concentrated on the variables, where a highly dispersed and thus easier item shows a wide spread on the endogenous variables. *Effect configuration* is understood as order and alignment of effects in a given subsystem and a rather ergometric question. Finally, we assume that *starting and target values* influence the detectability of effects. However, no a priori hypothesis can be inferred for the nature of this effect. As it is not possible to consider all aspects and their dependencies simultaneously, quality of effects, quantity of effects, strengths of paths and variable dispersion are chosen as potentially most relevant and incorporated into a balanced repeated measure ANOVA-design to test their impact on participants' performance and hence task difficulty. Thirty subjects from the target population are sampled to attain sufficient statistical power. Furthermore, through incorporating particularly chosen items, approximate statements concerning the role of number of variables and initial and target values can be made.

If – at least in the long run – complex problem solving can be nomothetically classified and established as a valid construct it might be relevant in virtually all areas involving prediction or explanation of cognitive performance. In the context of educational large-scale assessments, a detailed analysis of factors determining difficulty as described yields important information for item construction and is a prerequisite for a formally and theoretically valid testing device for individual competence levels in complex problem solving.

Activation of Learning Strategies When Writing Learning Protocols: The Specificity of Prompts Matters

Inga Glogger, Rolf Schwonke, Lars Holzäpfel, Matthias Nückles, and Alexander Renkl

University of Freiburg, Germany, Institute of Psychology, Engelbergerstr. 41, 79085 Freiburg, glogger@psychologie.uni-freiburg.de

Writing learning protocols has proven to be an effective instrument to foster self-regulated learning. A learning protocol typically represents a written explication of one's own learning processes and outcomes. In writing a learning protocol, students are asked to organize main ideas, explain concepts with concrete examples, and link new learning material to everyday life. In addition, students are asked to monitor their understanding and to formulate questions to ask in the next lesson. In other words, students are asked to apply learning strategies during writing. The results of Nückles, Schwonke, Berthold and Renkl (2004) among others, however, suggest that even university students show hardly any cognitive or metacognitive learning strategies without adequate support. Prompting has proven to be an effective instructional method to activate cognitive and metacognitive processes during learning. The assumption in prompting is that learners already possess certain abilities, but do not show them spontaneously. In writing learning protocols, prompts have proven to overcome this so called production deficiency (Flavell, Beach, & Chinsky, 1966) – at least for university students (e.g., Berthold, Nückles, & Renkl, 2004). Results of a pilot study with 9th grade students of a German secondary school revealed, however, that a relatively unspecific prompting that was found to be effective for university students did not support younger secondary school students in writing better learning protocols. These unspecific prompts asked for learning activities in general (e.g., to link new learning material to prior knowledge), but did not suggest concrete learning strategies (e.g., to find an example for a new concept). If production deficiencies are the reason for the lack of showing learning strategies, more specific prompts should help to overcome them more easily. Hence, the question arose whether for less experienced students the prompts would have to be more specific. More specific prompts, however, might keep students from using individual learning strategies. Therefore, a subsequent question was whether more specific prompts constrict the diversity of learning strategies.

Jörg Zumbach · Neil Schwartz · Tina Seufert ·
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