Gaining Meta Understanding in Complex Situations
Development of an Evaluation Template

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Pandemics and the climate crisis highlight the increasing importance of the ability to deal with complex situations. According to Ackhoff, "we fail more often because we solve the wrong problem than because we solve the right problem wrong" [1]. This is consistent with the literature showing that people have difficulty in sufficiently understanding complex situations or problems [2,3,4]. Based on this deficient understanding, decisions are made that often fail to have the desired effect in the long term or at all. This phenomenon is known as policy resistance [4], which describes the tendency for solutions to fail due to the system's reaction to the measures themselves [2,3,4]. The literature has offered various explanations for the emergence of deficient understanding, such as bounded rationality [5] and reductionist thinking, and for the maintenance of deficient understanding, such as hypothesis-confirming (biased) information gathering and dogmatic reinforcement [2,3]. To counteract inadequate understanding of complex situations and the resulting policy resistance, tools such as data dashboards, causal loop diagrams and system dynamics simulations are increasingly being used. These can help to overcome cognitive limitations. They also make it possible to externalize the mental models of individuals and thus communicate them better and develop shared mental models for teams [4]. Furthermore, simulation models can be used to examine dynamic behavior in the model and test policies and interventions. Despite the many advantages offered by these tools, it should be kept in mind that the understanding of real-world situations is often based on representations of the real-world situation. Consequently, it should be assessed how appropriately the real-world situation is represented, how reliable these representations are, and how appropriate and reliable the resulting understanding is, on which decisions for interventions are ultimately based.

"All models are wrong, but some are useful." George Box
Following this statement, we could also say: "All ideas and understandings of complex situations are wrong, but some are useful". The question is how we determine which tools or models are appropriate or useful and, consequently, which understanding is appropriate or useful. Consequently, in this paper, we argue that it is not only important to enable a (systemic) understanding of a complex situation, but that it is equally important to encourage the development of a certain meta-understanding. That is, understanding how well an existing visualization reflects a complex situation and therefore how well the situation can be understood and how much confidence should be placed in it. Why is this important?

In the field of automation psychology, it is assumed that too much trust (over trust) in automation goes hand in hand with a high degree of reliance and compliance. This means that people rely on automation and follow its recommendations without checking the information upon which they are relying [6]. This results in an inappropriate use of the automated tool (misuse). Or people don't trust the tool (distrust) and don't use it (disuse). Lee & See call the desired level of trust "calibrated trust" [7]. This means that the level of trust corresponds to the tool's scope of performance. In other words, people know the tool's capabilities and limitations and therefore use it in an appropriate way.

To achieve this, we propose a method or template for evaluating the scope of performance of existing tools, such as data dashboards, causal loop diagrams and system dynamics simulations, so as to gain a meta-understanding. That is, to understand how well a tool reflects a complex situation and therefore how well the situation can be understood and how much trust can be placed in it.

The term meta-cognition refers to the awareness of one's own cognitive processes. According to Flavell [8], two dimensions can be distinguished: meta-cognitive knowledge and meta-cognitive monitoring and self-regulation.

Regarding the first one, Flavell suggests four sub-dimensions: personalized knowledge, task-related knowledge, strategic knowledge and meta-cognitive sensations. The first of these is knowledge about one's own thinking and memory. The last is awareness of how easy or difficult the tasks are. Task knowledge refers to knowing what needs to be done and what the requirements of the tasks are. Strategic knowledge is knowledge that can be used to evaluate whether an approach is suitable for completing the tasks.

To develop an evaluation template that can be used to assess the scope of performance of an existing tool, we initially focused on identifying task knowledge. That is, what should be known or what questions must be answered to understand a complex situation, and what information is needed to answer these questions.

From a systemic perspective, complex situations arise through interacting systems of systems. Therefore, to identify relevant questions and information needed to understand complex situations (task knowledge) we conducted a literature review on systems, systems thinking and also on data and information quality [2-4, 9-26]. In summary, systems are "…a set of elements or parts that are coherently organized and interconnected in a pattern or structure that produces a characteristic set of behaviors, often classified as its 'function' or 'purpose' " [9, p.188]. Similar to Meadows [9}, Crawley [10] proposes the following essential characteristics of systems: Systems are composed of entities (systems) and relationships. Each has a form and a function. The form states what the system or relationship is and enables its function. The function indicates what the system or connection does or why it exists. The formal and functional structure, from which the form and function of the system emerges, results from the composed entities and relations [10]. According to the iceberg representation [9,11,14,15] systems can be perceived and understood at different levels. At the event level, the observer can perceive and understand the performance of the underlying system functions or system states. If these are observed over a longer period, trends and patterns of change can be recognized that allow conclusions to be drawn about relationships between system functions. If information about optimal performance measures or system states is available, these can be compared with the actual ones. This makes it possible to recognize whether the current events are to be classified as problematic or unproblematic. To understand why problematic or unproblematic events occur, the formal and functional structure of the underlying system of systems should be explored, analyzed, visualized and understood.

Based on the insights gained, we have created a list of questions that should be answered to understand complex situations, as well as the information needed to answer these questions. For each of these questions and information needs, we have added a question and an information need regarding information and data quality. For example, to know what is happening, people need information about events, i.e. data about the output of system functions. To know how trustworthy this knowledge about the situation is, people need information about the data quality, e.g. about the completeness, validity, objectivity and reliability of the data. To understand why certain system outputs (events) emerge, people need information about the functional or input and output structure. To understand how reliable the represented structures are, people need information about the completeness, validity, reliability and objectivity of the structural information.

We have developed an initial draft of an assessment template that reflects this task knowledge. To assess the quality of the event data and structure, we are working on additional assessment templates to be integrated into the design. Based on insights from the literature on systems and systems thinking, the evaluation template for structure will check for the presence of important structural characteristics of complex situations, such as functional openness, interdependencies that form reinforcing and balancing feedback loops, structural dynamic or self-organization and the partial lack of transparency in the structure and the associated uncertainties.

The ultimate goal is to use these templates to assess the scope of existing tools and to present the strategic knowledge gained to decision-makers. The assumption associated with this is that by uncovering discrepancies between the available and required information, decision-makers can understand how comprehensively and reliably a tool reflects a complex situation and how comprehensively and reliably the resulting understanding is, on which decisions for interventions are ultimately based. In future work, an experimental investigation of these assumptions is planned.

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REFERENCES

(1) R. Ackoff, "The future of operational research is past", Journal of the Operational Research Society Vol. 30, 1979 pp. 93–104
(2) D. Doerner & H. Schaub, "Errors in Planning and Decision Making and the Nature of Human Information Processing", in Applied Psychology: An International Review Special Issue on Human Error, 1994, pp. 433 – 453.
(3) D. Dörner, Die Logik des Misslingens: Strategisches Denken in komplexen Situationen, 15th ed. Reinbek/ Hamburg: Rowohlt Taschenbuch Verlag, 2018
(4) J. D. Sterman, Business Dynamics. System Thinking and Modeling for a Complex World, McGraw-Hill Companies, Inc., 2000
(5) H.A. Simon, Herbert, A Behavioral Model of Rational Choice. In: *The Quarterly Journal of Economics* 69 (1), 1955, S. 99.,
(6) R. Parasuraman & V. Riley, Humans and automation: Use, misuse, disuse, abuse. *Human Factors*, 39, 1997, pp. 230-253
(7) J. D. Lee & K.A. See, Trust in automation: Designing for appropriate reliance. *Human Factors*, 46, 2004, pp. 50-80.
(8) J. H. Flavell: Annahmen zum Begriff Metakognition sowie zur Entwicklung von Metakognition. In F. E. Weinert (Hrsg.), *Metakognition, Motivation und Lernen*, Stuttgart: Kohlhammer, 1984, pp. 23–30
(9) D.H. Meadows, Thinking in systems: A primer, 11th ed. White River Junction, Vermont: Chelsea Green Publishing, 2008
(10) E. Crawley, B. Cameron & D. Selva, System Architecture: Strategy and Product Development for Complex Systems, 1st ed. Pearson, 2023
(11) P. Senge, The Fifth Discipline. The Art and Practice of Learning Organization. New York, NY: Doupleday/Currency, 1990.
(12) P. Gomez, F. Malik, K.H. Oeller, Systemmethodik: Grundlagen einer Methodik zur Erforschung und Gestaltung komplexer soziotechnischer Systeme, 2. Bd., Bern/Stuttgart, 1975
(13) F. Malik, Strategie des Managements komplexer Systeme. Ein Beitrag zur Management-Kybernetik evolutionärer Systeme, 10th ed., Bern:Haupt, 2008
(14) D. Kim, Introduction to systems theory, Pegasus Com., Inc., 1999
(15) E. Cunliff, "Connecting Systems Thinking and Action", in The Systems Thinker, Vol.12(2), Pegasus Communications, Inc.,2004
(16) L. von Bertalanffy, General System Theory: Foundations, Development, Applications, New York: George Braziller, 1968
(17) H. von Foerster, „Abbau und Aufbau", in Lebende Systeme, F. B. Simon, ed., Heidelberg: Springer Verlag, 1988, pp. 19–33.
(18) D.J. Snowden & M.E. Boone, "A leader's framework for decision making", Harvard Business Review, Vol.85 (11), 2007, pp. 68-76.
(19) A. Rempfer & N. Uphues, Sozialökologisches Systemverständnis: Grundlage für die Modellierung von geographischer Systemkompetenz. *Geographie und ihre Didaktik | Journal of Geography Education,* 38(4), 2010, S. 205–217,
(20) Y. Merali & P. Allen, "Complexity and systems thinking" in The SAGE Handbook of Complexity and Management, P. Allen, S. McGuire, B. McKelvey B. ,ed., London: Sage, 2011
(21) H. Maturana & F. Varela, Autopoiesis and Cognition: The Realization of the Living, 2nd ed., 1980
(22) B. Richmond, "System Dynamics/Systems Thinking: Let's Just Get On With It", System Dynamics Review 10(2/3), 1994, pp.135-157.
(23) P. Senge, The Fifth Discipline. The Art and Practice of Learning Organization. New York, NY: Doupleday/Currency, 1990.
(24) R. Arnold & J. Wade, "A Definition of Systems Thinking: A Systems Approach", Procedia Computer Science, Vol.44, 2015, pp. 669–678
(25) K.A. Stave & M. Hopper, "What constitutes systems thinking? a proposed taxonomy", Proceedings of the 25th International Conference of the System Dynamics Society. Boston, Massachusetts, 2007

(26) S. Traeber-Burdin & M. Varga, How does Systems Thinking support the Understanding of Complex Situations? IEEE International Symposium on Systems Engineering (ISSE), Vienna, Austria, October 24 26, 2022
(27) Y. W. Lee et al., AIMQ: a methodology for information quality assessment, *Information & Management*, 40, Elsevier, 2002, pp. 133–146