

CODEM: A Microworld Platform for Research, Training, and Assessment in Complex Problem-Solving

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ABSTRACT

Complex problem-solving (CPS) skills—the ability to comprehend, manage, and adapt to complex, evolving situations—are essential in the 21st-century workplace. However, evidence shows that individuals are cognitively and computationally limited in managing complex systems characterized by multiple interdependent variables and conflicting goals. Traditional laboratory tasks are too simple and often fail to capture these properties. Microworlds offer controlled complexity: they can reproduce properties of complex systems but remain tractable for systematic manipulation and data collection. We present CODEM (COmplex DEcision Making), a microworld designed to simulate complex dynamic systems and trace the cognitive processes underlying CPS. The platform, now updated for online deployment, supports performance analysis, cognitive process tracing and intelligent tutor extensions. CODEM has three key applications: as a research tool for studying CPS and decision heuristics, as a training tool for developing systems thinking skills, and as a personnel selection tool assessing the capacity to manage complexity.

Keywords: Cognition, Microworld simulation, Complex problem solving, System dynamics

INTRODUCTION

Complex problem-solving (CPS) has emerged as a defining cognitive skill for the digital era. It encompasses the ability to comprehend dynamic systems, manage interdependent goals, and adapt under uncertainty. CPS also requires critical thinking, defined as the capacity to evaluate information, question assumptions, and make reasoned judgments under conditions of ambiguity (Funke, 2025). Yet, managing such complexity poses a profound cognitive challenge that often exceeds the limits of human reasoning and working memory. Microworlds are open-ended, computer-simulated, rule-based environments that reproduce the dynamics of real-world systems while maintaining experimental control (Gray, 2002; Brehmer, 1992). They allow researchers to study how people reason, plan, and

act under conditions of complexity and uncertainty—conditions in which traditional laboratory tasks are too simple and field studies too uncontrolled. Building on this approach, CODEM (COmplex DEcision Making) is a microworld platform designed to simulate dynamic decision environments, trace cognitive processes, and support applications in research, training, and assessment of complex problem-solving skills. Insights from such simulations highlight the importance of developing tools and training approaches that help individuals better cope with complex problems—or at least raise awareness of the cognitive barriers that hinder decision-making in dynamic and uncertain environments.

THE COGNITIVE CHALLENGE OF DEALING WITH COMPLEXITY

Decades of research in complex problem-solving and dynamic decision-making show that even well-trained individuals, like engineers, policymakers, or elected officials, often fail to manage complex and dynamic systems effectively (Dörner & Funke, 2017; Sternberg, 2024). Across microworld experiments, participants perform only marginally above random baselines despite comprehension of task rules and sustained motivation. These findings support the view that complexity constitutes a fundamental cognitive barrier rather than a temporary performance deficit (see Béchard et al., 2025).

The Properties of Complexity

Complexity arises from the interplay of structural, temporal, and informational factors whose interactions produce higher-order consequences, such as non-linearity, emergence, and adaptive dynamics (Ladyman & Wiesner, 2020; see Table 1). These emergent properties, by multiplying interdependencies and feedbacks, often exceed the limits of human cognitive processing capacity (Funke, 2021; Simon, 1972). In microworld environments such as CODEM, these properties can be manipulated to examine their impact on task performance.

Table 1: Complexity properties operationalized in CODEM and cognitive challenges.

Property	Definition	Cognitive Challenge
Multiplicity	Numerous variables and goals (<i>polytely</i>)	Working-memory overload; failure to process interactions beyond four relations
Interconnection	Dense causal linkages	Misjudgment of indirect effects; local focus bias
Feedback Loops	Recursive positive/negative influences	Oscillations, reactive control, and misinterpreted delays
Non-linearity	Non-proportional cause-and-effect relations	Failure of proportional reasoning; erratic correction
Delays	Temporal lags between action and outcome	Misattribution of cause and effect; over-/under-correction
Opacity	Partial information visibility	Reliance on heuristics; confirmation bias

Cognitive Limitations and Decision Biases

While these structural, temporal, and informational properties define what makes complex systems inherently difficult to control, their effects must be understood relative to the limitations of the human cognitive system (see Table 2). The failures observed in complex problem-solving can be traced back to inherent limits in human cognition rather than knowledge gaps. These constraints include working memory limits that hinder the simultaneous manipulation of as few as four interdependent variables at once (Halford et al., 2007), heuristic shortcuts that misrepresent nonlinear dynamics (Cronin et al., 2009), the tendency to shift from reflective to heuristic decision-making (Georgalos & Nabil, 2025), and poor integration of delayed feedback (Lurie & Swaminathan, 2009; Sterman, 1989). Humans also tend to cope with overwhelming complexity by (over)simplifying their mental models, often by overemphasizing the causal power of a single factor (see B  chard et al., 2023). As Schoppek (2019) observes, this reductionist strategy provides a false sense of control and leads to systematic misjudgments.

Table 2: Common cognitive and behavioral patterns in complex problem-solving.

Behavioral Patterns	Description/Consequences
Single-cause reasoning	Oversimplifying problems by isolating one cause and ignoring interactions.
Symptom treatment	Acting on visible outcomes instead of addressing root causes, leading to recurrence.
Linear projection	Assuming proportionality and steady trends while neglecting feedback effects.
Short-termism	Prioritizing immediate results while disregarding delayed consequences.
Confirmation bias	Ignoring counter-evidence and reinforcing prior assumptions.
Overconfidence	Overestimating understanding of complex systems.
External attribution	Blaming external factors instead of revising one’s strategy.

The context of uncertainty characteristic of complex problem-solving further exacerbates reasoning failures. Indeed, as Funke (2025) suggests, increasing complexity and the inherent uncertainty of the future drive people toward reductionist interpretations and fast, simplifying judgments. As interdependencies and feedback loops accumulate, mental models collapse, leading to heuristic reasoning and local rather than systemic control. People tend to focus on visible, short-term cues and neglect time delays, indirect effects, and second-order consequences. Additionally, individuals show little metacognitive awareness of these failures and often display overconfidence in flawed mental models (D  rner & G  ss, 2022). According to Fiedler et al. (2023), individuals tend to process available information uncritically, assuming its validity without questioning bias, sampling error or reliability. This recurrent failure reflects *metacognitive myopia*, a lack of critical monitoring and control over one’s own reasoning processes. Such metacognitive miscalibration is characterised by overconfidence,

perseverance in failing strategies, and the misattribution of outcomes to external causes, symptoms of poor metacognitive monitoring and limited volitional control.

CODEM: A MULTI-PURPOSE PLATFORM

Microworlds have become a cornerstone in the study of complex problem-solving (CPS) and decision-making (Herde et al., 2016). Pioneered by Dörner and colleagues (e.g., Tailorshop), they provide dynamic, rule-governed environments in which participants must regulate interdependent variables over time to achieve multiple goals (Brehmer & Dörner, 1993). Unlike static cognitive tasks, microworlds embed feedback, uncertainty, and delayed consequences, thereby reproducing properties of real-world complexity. Over the past three decades, they have been used to investigate cognitive load, strategy development, and adaptive expertise (Funke, 2010). In the educational context, microworlds also serve as experiential learning environments that foster systems thinking (Qudrat-Ullah, 2014). This dual research-and-pedagogical function provides the foundation for CODEM—a flexible platform for systematically exploring, training, and assessing human performance in complex dynamic systems.

CODEM represents two decades of interdisciplinary research on human cognition in complex environments. In the present work, CODEM has now been updated to allow its deployment as a web-based modular simulation platform for dynamic decision research. It comprises six main interfaces—Situation, Relations, Prediction, Decision, Info, and Notes—each designed for cognitive process tracing (measure of info acquisition behaviors and duration; see Lafond et al., 2012). The scenario editor allows for full customization without programming expertise: the scenario designer can define variables, causal relations, feedback loops, opacity, and delays. Data logging captures every player action for behavioral analytics. The system supports both single-player and multiplayer configurations. Examples of possible scenarios include interagency operations, ecosystem or organisation management and societal governance. These simulations model the same principles of dynamic complexity and allow researchers to study information seeking, strategic reasoning, and learning under uncertainty (see Figure 1).

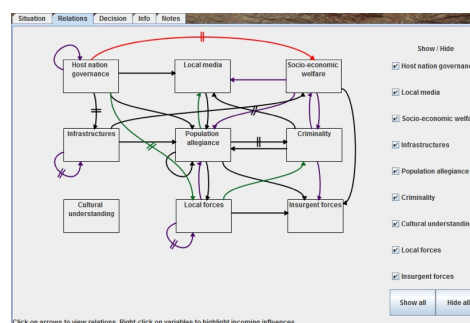


Figure 1: Relations tab displaying interconnections between variables allowing users to explore variable interactions. The red arrow indicates the active selection. Green and purple arrows refer to positive and negative effects. A double bar represents delayed impacts.

Depending on the configuration, participants engage in one of two task types. In the control mode, the goal is to stabilize the system by bringing all key factors into an equilibrium or “green zone,” (see Figure 2) similar to the goal of other microworlds such as Ecopolicy (see Lafond et al., 2012). In the prediction mode, participants do not intervene but must anticipate how the system will evolve over time based on its causal structure and initial conditions. This mode focuses on systems understanding and forecasting accuracy (see Forester, 1994).

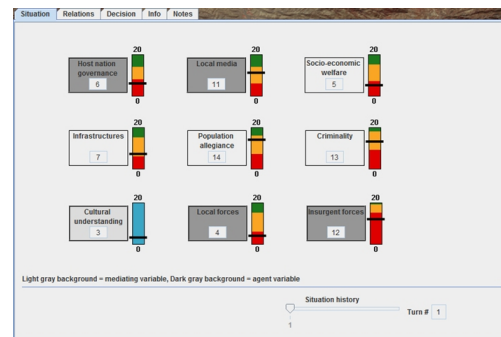


Figure 2: Situation tab in CODEM showing variable states and color-coded indicators (green, orange, red) for each system dimension.

CODEM as a Testbed for Research and Development

CODEM was conceived as an experimental platform to analyze human decision-making under controlled yet ecologically valid forms of complexity. It supports experimental manipulation of multiple system features (e.g., number of variables, feedback delays, opacity, and uncertainty), enabling the decomposition of how these properties influence cognitive performance, strategy, and learning.

Data logs record every decision, prediction, and action across turns, offering a detailed trace of cognitive processes. Measures include performance (goal attainment), process indicators (information-seeking frequency, feedback consultation), and metacognitive variables (confidence judgments, calibration accuracy). These indicators can be combined into indices of cognitive adaptability and system understanding. By tracing how individuals explore, infer, and adjust within such environments, microworlds offer a window into the mechanisms underlying human cognition—and its frequent breakdown—under complexity.

CODEM can also be employed as a research and development environment for testing decision-support systems (DSS) and explainable artificial intelligence (XAI) prototypes. Its modular architecture allows real-time integration of AI-based cognitive aids designed to enhance situation awareness, recommend adaptive strategies, or visualize causal structures. These integrations provide a human-in-the-loop framework to study how users interact with automated reasoning and explanations under uncertainty.

This capability positions CODEM as a testbed for evaluating not only human cognition but also the transparency, trust, and usability of emerging XAI tools (see Tremblay et al., 2017).

CODEM as a Training Tool and Interactive Learning Environment

CODEM was also designed to serve as a training environment aimed at improving cognitive readiness for complexity. The Interactive Learning Environment (ILE) component integrates interactive simulation, intelligent tutoring, and structured debriefing within a single platform. Training is designed around five skills: (1) system thinking and feedback reasoning, (2) adaptive problem-solving, (3) situation awareness, (4) metacognitive monitoring, and (5) transfer of learning. These skills collectively constitute cognitive readiness—the ability to anticipate, adapt, and sustain effective performance under uncertainty.

The pedagogical design follows a learning approach that promotes conceptual insight and metacognitive reflection. The training system includes four modules:

- **Tutorial Module:** Introduces the concept of dynamic complexity and teaches the user interface using introductory scenarios.
- **Information Module:** Presents conceptual content (feedback loops, time delays, leverage points) integrated with the ongoing scenario.
- **Intelligent Tutor:** Monitors behavioral indicators in real-time. When poor strategies such as reactive or goal-distance allocation patterns are detected, the tutor intervenes with targeted prompts encouraging systemic thinking.
- **Debriefing Module:** Provides a metacognitive review at the end of each scenario. It contrasts predicted versus actual outcomes, displays efficiency scores, and highlights optimal strategies.

Results from Lafond et al. (2014) showed that training with CODEM significantly increases the adoption of adaptive heuristics such as Net-Think, a systemic meta-heuristic balancing short-term interventions with long-term systemic control. In controlled studies, participants trained under CODEM improved their decision strategies, showing greater exploration, anticipation, and feedback use.

CODEM as a Psychometric Tool

In modern personnel selection, organizations increasingly seek to evaluate more than technical expertise or general mental ability. The capacity to navigate uncertainty, manage interdependent goals, and adapt from feedback—collectively captured under the construct of CPS—is now seen as a key predictor of success in dynamic, innovation-driven workplaces (Funke, 2021). CODEM captures both performance outcomes and process-level behaviors, including information-seeking, exploration, and feedback integration, offering insight into how individuals reason rather than simply how well they perform (Lafond et al., 2012).

As a game-based assessment, CODEM may increase engagement and perceived fairness (Landers & Sanchez, 2022) while reducing faking effects. Behavioral analytics enable multidimensional scoring based on exploration efficiency, metacognitive regulation, and cognitive flexibility, aligning with advanced game analytics and psychometric modeling (DiCerbo, 2017). By combining ecological realism, adaptive measurement, and positive candidate experience, CODEM bridges cognitive science and applied HR practice. It complements traditional measures like GMA by assessing reasoning in motion—a dynamic indicator of system thinking and adaptability (Hodgetts et al., 2023).

Another advantage of CODEM is its capacity for scenario co-creation with organizational stakeholders. Tailoring the storyline, variables, and performance indicators to a specific role (e.g., policy analysis, operations management, or crisis coordination) increases both face validity and situational relevance. Customization ensures that participants engage with challenges that mirror the decision structures, trade-offs, and constraints of the target work activities.

CONCLUSION

As a microworld platform, CODEM unifies experimental precision, instructional innovation, and applied assessment. By reproducing the essential features of complexity—feedback, delay, interconnection, and emergence—CODEM provides researchers, educators, and practitioners with a robust tool, now deployable online, to study, train, and evaluate adaptive decision-making. It stands as both a cognitive laboratory and a human-centered assessment system for understanding how individuals navigate complexity in an increasingly interconnected world.

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