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Beyond Psychometrics: The Difference between Difficult Problem Solving and Complex Problem Solving

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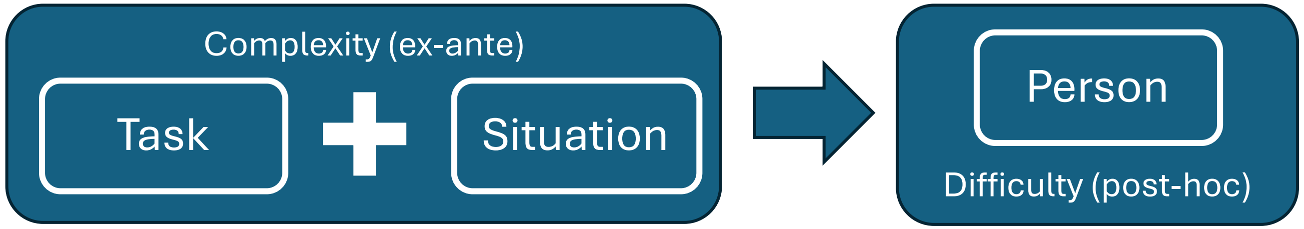
CBMM Journal Club

Motivation & Aim



- Complex problem solving (CPS) – no clear definition
- Existing literature looks at CPS *psychometrically*
  - Complexity = observed performance (descriptive & circular)
  - E.g., Problem solvers perform worse in contextual tasks (“semantic effect”), so the tasks are labelled “complex”
  - This does not explain individual differences in behaviour and performance
- Definitions:
  - **Complexity**: ex-ante considerations of the cognitive demands imposed by the Task and Situation (conceptual & predictive)
  - **Difficulty**: post-hoc analysis of the Person-level differences (experiential & statistical)
- **Aim**: To differentiate complexity and difficulty in CPS using the Person-Task-Situation (PTS) framework

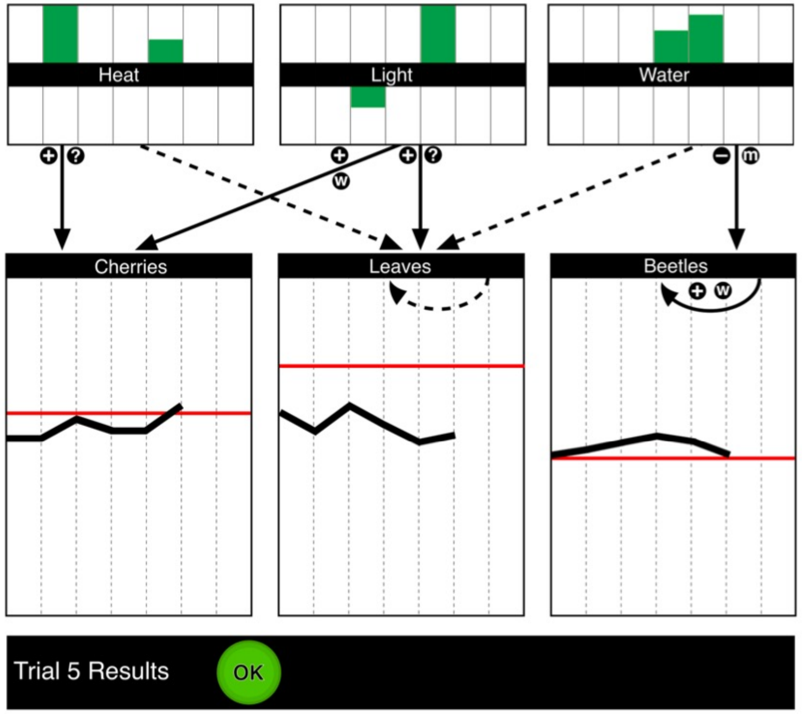
Hypotheses

- **Systematicity Hypothesis**: high semanticity (high situational complexity) leads to less systematic exploration behaviour (greater difficulty)

- **Complexity-Difficulty Hypothesis**:
  - *Complexity account*: eliminating pre-existing causal structure in a system is more cognitively demanding than constructing the relationships from a blank slate
    - Full slate performance << Blank slate performance
    - High semanticity performance << Low semanticity performance
  - *Difficulty account*: problem solvers are capable of CPS, but they do not adopt the appropriate exploration strategy
    - Construct-irrelevant difficulty

ML's comment: It could be the fact that the problem is more cognitively demanding so problem solvers use less systematic heuristics

Experiment: CPS Task (1/2)



- **Task qua task** (inputs)
  - 3 inputs
  - 3 outputs
  - 12 possible relationships (solution = 6)

- **Task as behaviour requirement** (instructions)

Exploration Phase:

Find the relationships between variables

- 2 cycles, 7 trials each
- Free to change

Control Phase:

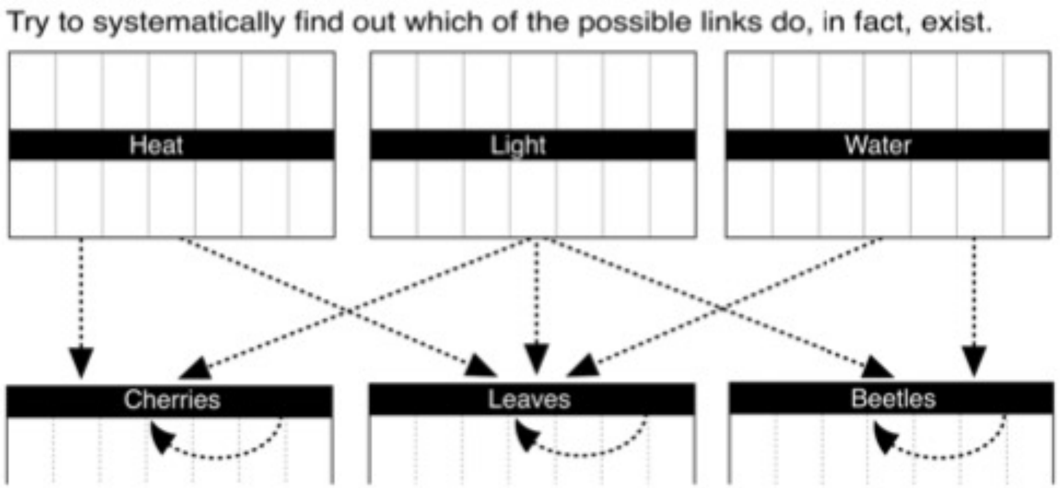
Maintain the target state given the relationships

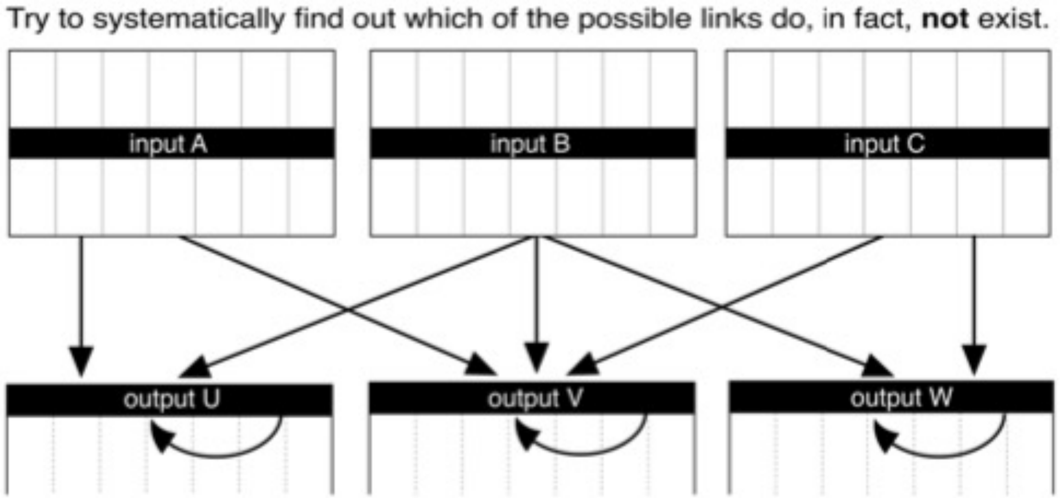
- 2 cycles, 7 trials each
- Match target states (red lines)

Experiment: CPS Task (2/2)

- Varying instructions (task complexity)
  - **Blank slate (compile)**: assumes no relationship exists
  - **Full slate (eliminate)**: assumes all relationships exists

- Starting from a full slate is more complex than from a blank slate -> need to eliminate presumptions



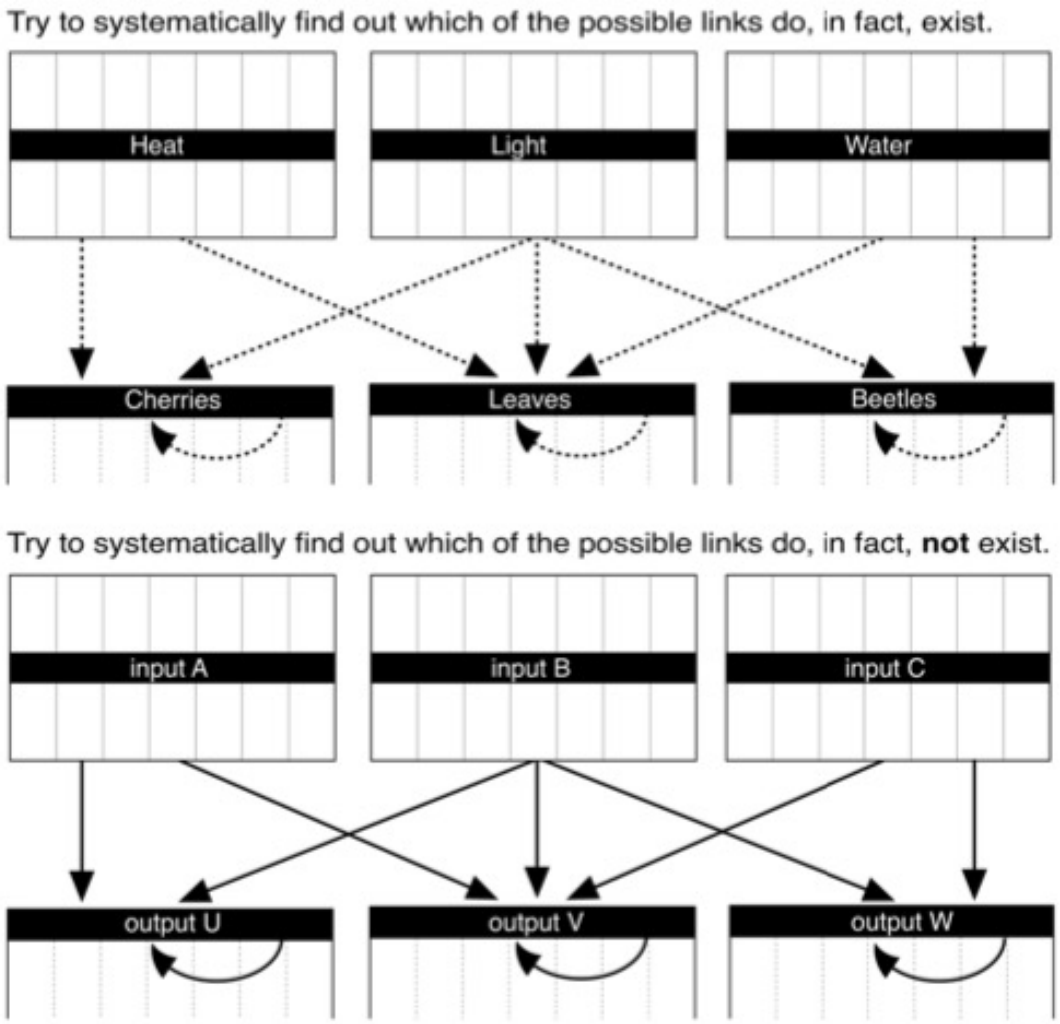


Experiment: CPS Situation

- Use the "semantic effect" to manipulate situational complexity
  - **High semanticity: Cherry Tree**
  - **Low semanticity: Black Box**

- High semanticity is more complex -> need to eliminate *more* presumptions

- All 12 possible relationships for "Cherry Tree" were expected to be equally likely to exist by the participants



Metrics

$$B_r = \frac{\text{False Alarm rate}}{1 - (\text{Hit rate}) - (\text{False Alarm rate})}$$

$$P_r = (\text{Hit rate}) - (\text{False Alarm rate})$$

$$avEuXr = \frac{1}{m}\sum_{t=1}^{m}\{1 - [\frac{\sqrt{\sum_{i=1}^{k}(\text{optimal}_{ti} - \text{actual}_{ti})^2}}{\sqrt{\sum_{i=1}^{k}(\text{pessimal}_{ti} - \text{optimal}_{ti})^2}}]\}$$

Metric	Definition	Interpretation
Bias Index $B_r \in [0,1]$	Tendency to guess that a relationship exists when it is uncertain	$B_r < 0.5$ = conservative response tendency (no relationship) $B_r > 0.5$ = liberal response tendency
Systematicity	Ordinal score of the exploration behaviour	2 = set all inputs to zero and change inputs individually; 1 = either set all inputs to zero OR change inputs individually; 0 = none of the above exploration strategies
Exploration performance $P_r \in [-0.98,0.98]$	Ability to detect the causal structure in a system (knowledge acquisition)	$P_r < 0$ = inaccurate knowledge $P_r > 0$ = more accurate knowledge
Control performance $avEuXr \in [0,1]$	Distance between actual and target state across all outputs	$avEuXr = 0$ = worst possible performance $avEuXr = 1$ = best possible performance

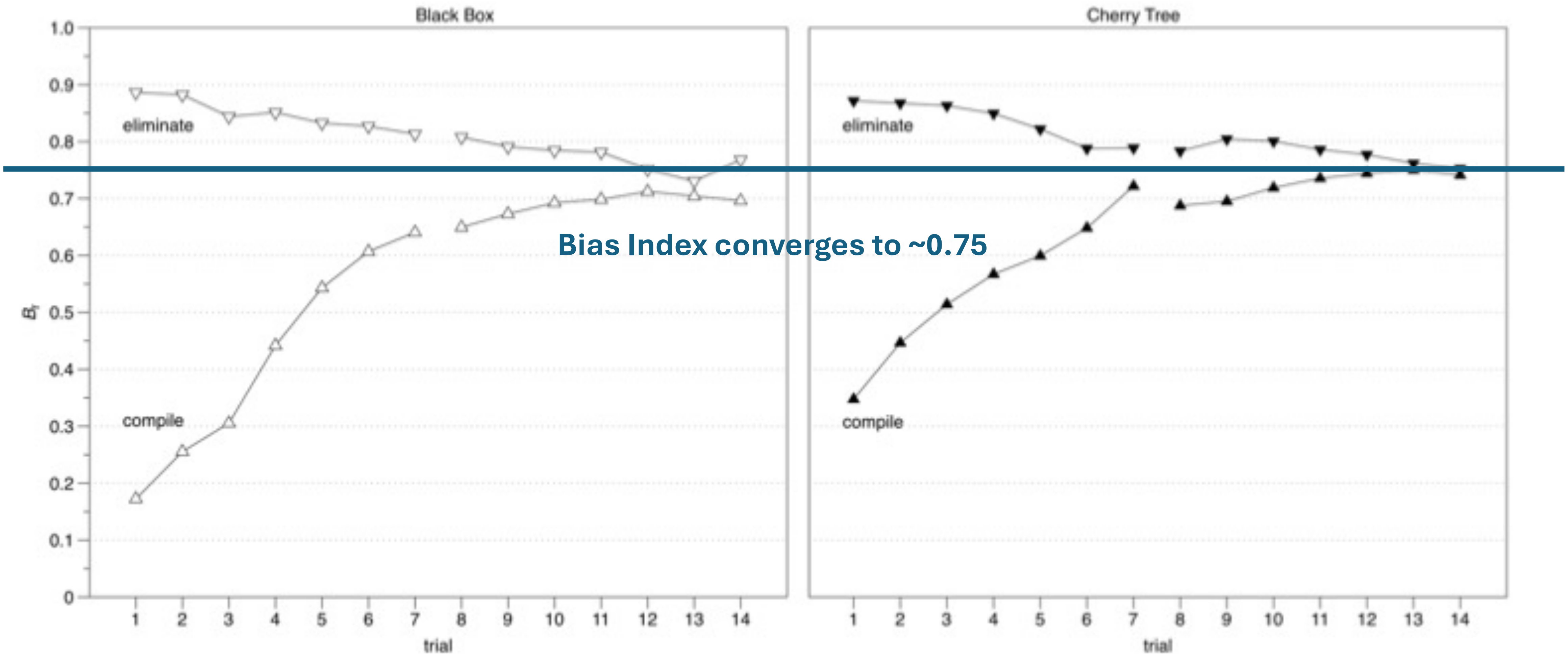
Descriptive Statistics:

- 240 university students in Australia (mean age 22.7 years)

TABLE 1 | Descriptive statistics.

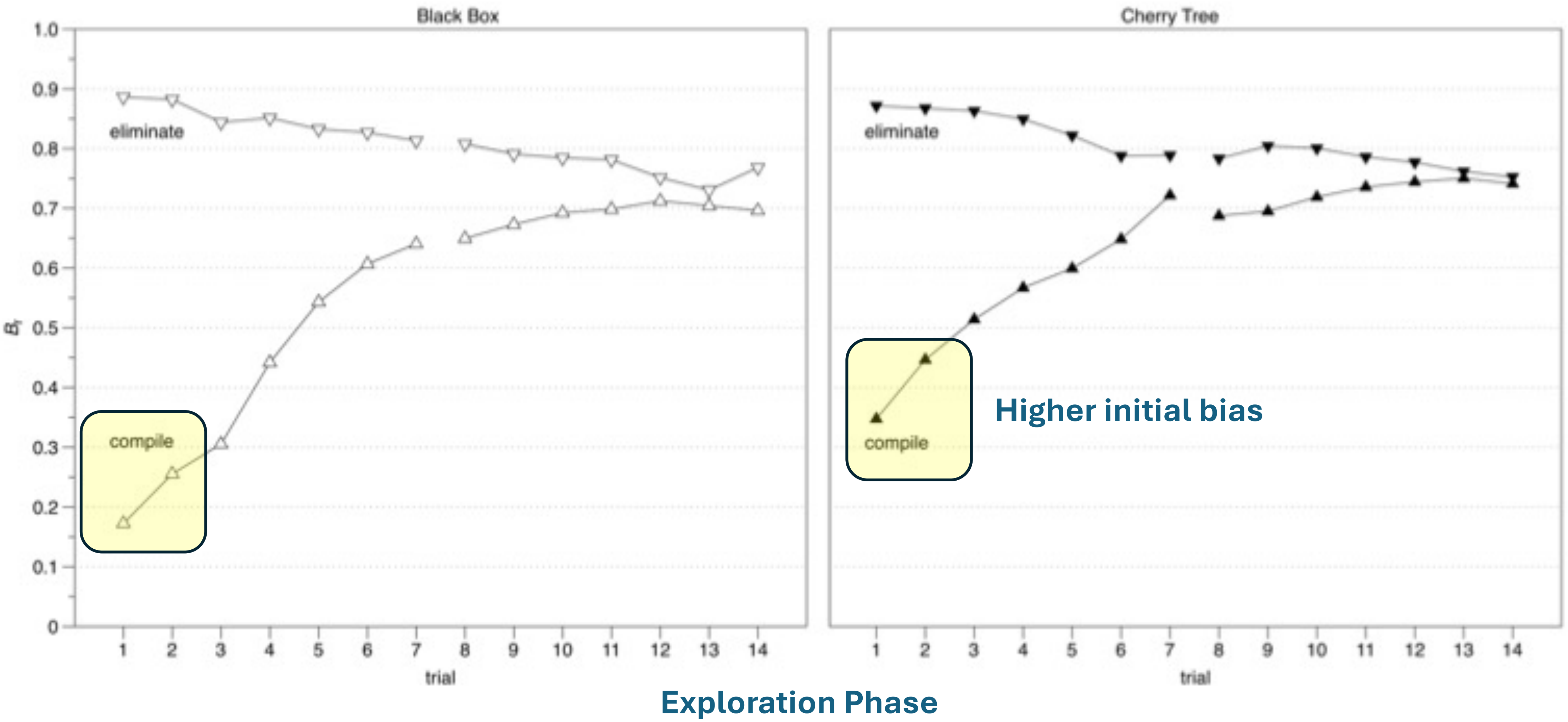
Conditions		
Semanticity	**Instruction**	***N***
Low (Black Box)	Compile	57
	Eliminate	59
High (Cherry Tree)	Compile	63
	Eliminate	61

Result 1a: Problem solvers were more likely to guess that a relationship exists

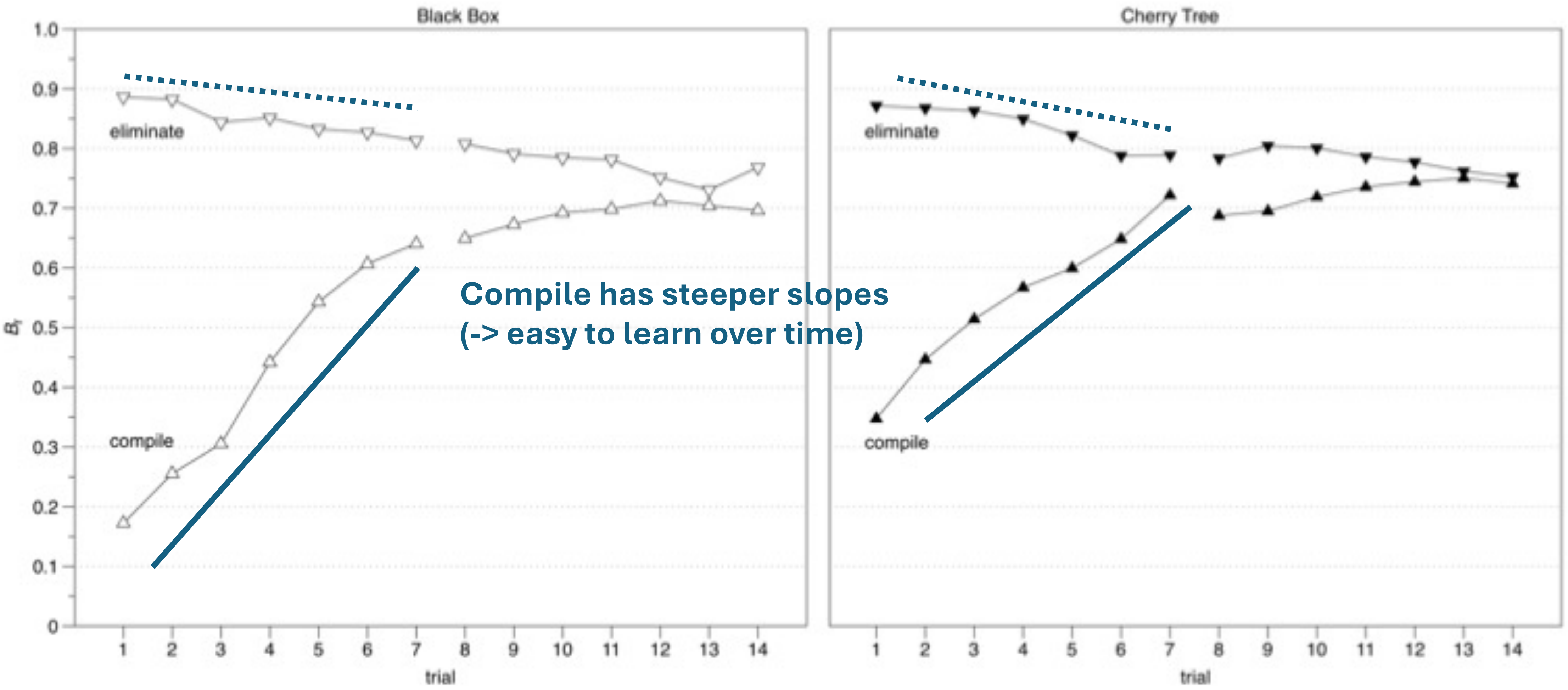


Exploration Phase

Result 1b: Problem solvers struggle to start with a blank slate in high semanticity condition



Result 1c: More complex to eliminate than compile relationships



Exploration Phase

Result 2: *Systematicity* – more systematic exploration in low semanticity conditions

TABLE 2 | Ordinal logistic regression of systematicity (VONAT) on semanticity and instruction.

	Estimate	*SE*	Wald χ^2	*df*	*p*	Odds ratio
Semanticity (Black Box vs. Cherry Tree)	0.804	0.251	10.256	1	0.001	2.24
Instruction (compile vs. eliminate)	–0.307	0.246	1.557	1	0.212	0.74

2.24 times more likely to systematically explore in the Black Box system

Result 3: *Complexity-Difficulty* – NO difference in performance when varying task complexity

TABLE 1 | Descriptive statistics.

Conditions			$F_{1,236} = 0.119$, $p = 0.730$	$F_{1,236} = 0.027$, $p = 0.870$
Semanticity	**Instruction**	***N***	**Knowledge acquisition P_r[14] *M* (*SD*)**	**System control *avEuXr M* (*SD*)**
Low (Black Box)	Compile	57	0.57 (0.30)	0.65 (0.12)
	Eliminate	59	0.41 (0.35)	0.60 (0.12)
High (Cherry Tree)	Compile	63	0.20 (0.25)	0.55 (0.09)
	Eliminate	61	0.33 (0.36)	0.59 (0.13)

Exploration Phase vs. Control Phase

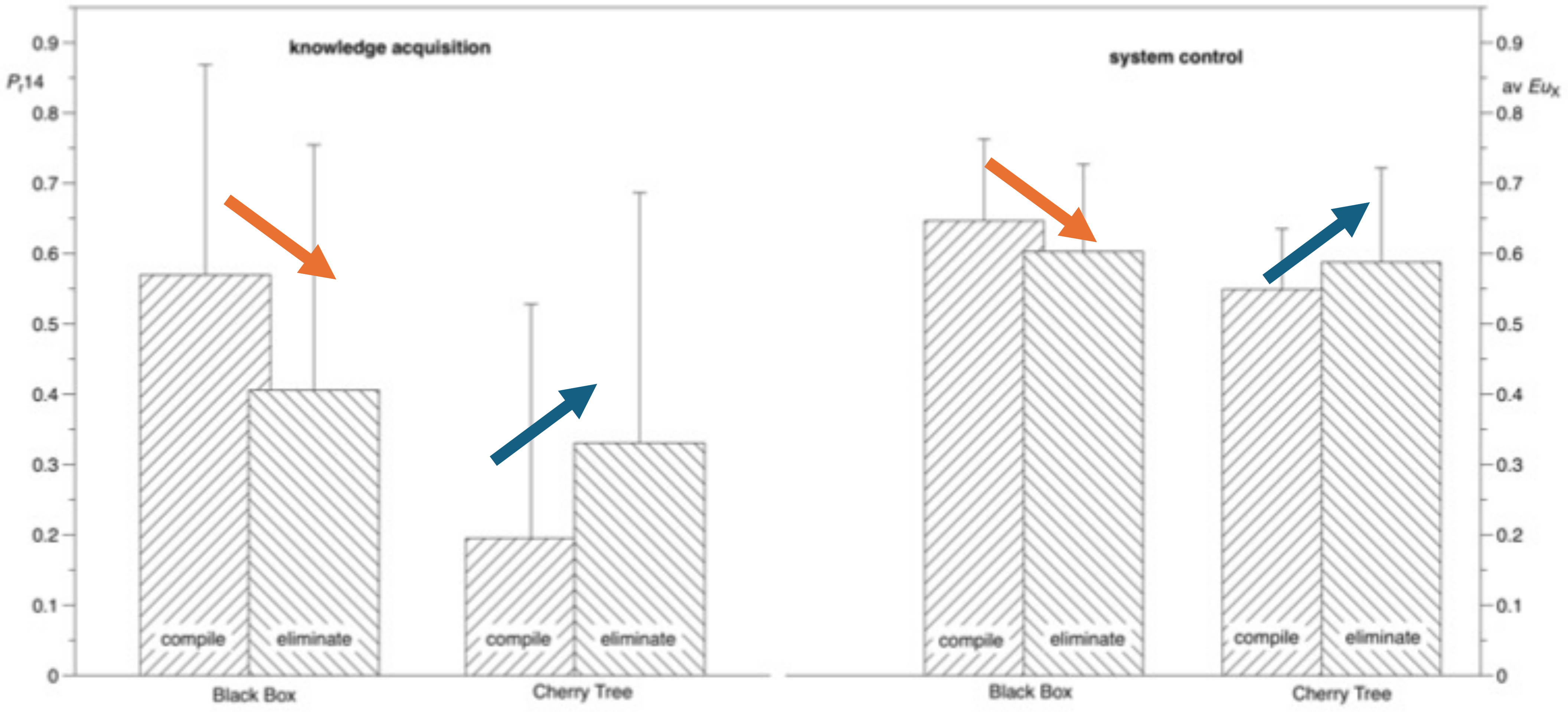
Result 4: *Complexity-Difficulty* – Worse performance in high semanticity conditions

TABLE 1 | Descriptive statistics.

Conditions			$F_{1,236} = 29.863$, $p < 0.001$	$F_{1,236} = 14.048$, $p < 0.001$
Semanticity	**Instruction**	***N***	**Knowledge acquisition P_r[14] *M* (*SD*)**	**System control *avEuXr M* (*SD*)**
Low (Black Box)	Compile	57	0.57 (0.30)	0.65 (0.12)
	Eliminate	59	0.41 (0.35)	0.60 (0.12)
High (Cherry Tree)	Compile	63	0.20 (0.25)	0.55 (0.09)
	Eliminate	61	0.33 (0.36)	0.59 (0.13)

Exploration Phase vs. Control Phase

Result 5: *Complexity-Difficulty* – greater complexity to supress presumptions in high semanticity conditions, especially instructed to start with a blank slate



Exploration Phase vs. Control Phase

Summary

- **Complexity ≠ Difficulty**

- Problem solvers perform worse in high semantic systems because of:
  - Greater situational complexity (increased cognitive demands): need to unlearn existing causal structure
    - More cognitively demanding to start with a blank slate
  - Greater difficulty: adopt less systematic exploration behaviours given the semantics (*due to greater situational complexity*)

ML's comment: It could be the fact that the problem is more cognitively demanding so problem solvers use less systematic heuristics

ML Thoughts

- Difficulty is measured in terms of observed behaviour: exploration strategy and performance
  - No measure of time/effort or perceived difficulty
  - Difficulty seems to be a function of complexity (cognitive demands) in this study but treated independently
    - Exploration behaviour is affected by cognitive demands

- Measures “ex-ante cognitive demand” -> CCT framework?

- Is there a difference in cognitive demands between the constructing and eliminating items in the KP task?
  - Suppose total item value and weight are provided

Exploration Phase:

Find the relationships between variables

- 2 cycles, 7 trials each
- Free to change

Control Phase:

Maintain the target state given the relationships

- 2 cycles, 7 trials each
- Match target states (red lines)

(Inst

Blank slate (Compile)

Situation (Semanticity)

Low (Black Box)

High (Cherry Tree)

Complexity (ex-ante)

Task + Situation

Person

Difficulty (post-hoc)

PTS Framework – Knapsack Problem

- Task
  - Task qua task (variables/inputs): set of items with values and weights
  - Task as behaviour requirement (instructions): find the set of items that maximise the value of the knapsack given a weight constraint

- Situation
  - Graphical representation of items/KP
  - Interface design
  - Online vs. offline KP (same instructions but different circumstances)

- Person
  - Individual KP solving strategies, IQ, age