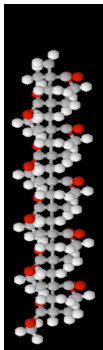
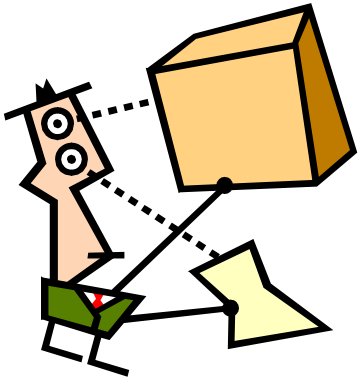


Exploring Heuristic Reasoning



Vicente Talanquer
Department of Chemistry and Biochemistry
University of Arizona

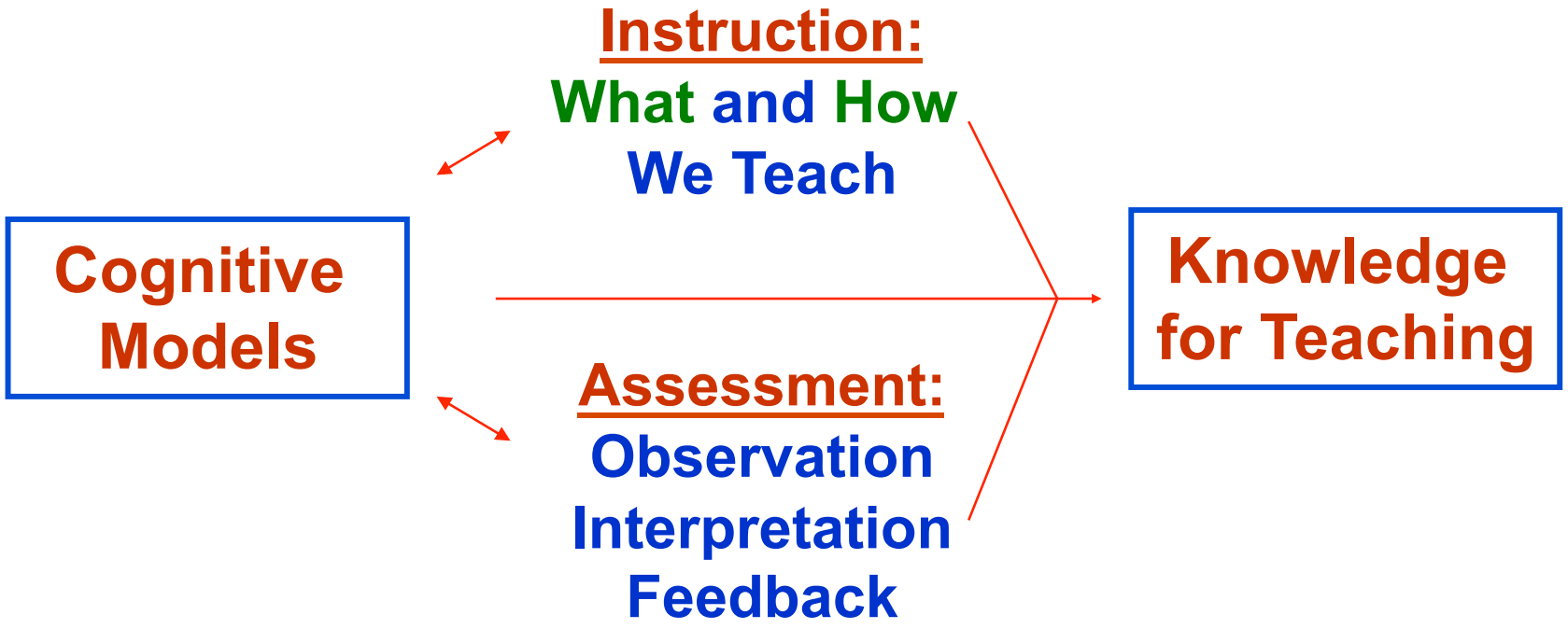
Our Interests

How does student thinking about "chemical entities" evolve?

Novices **Experts**

Our Goal

Generate cognitive models that can help us predict, explain, assess, and transform how chemistry students think.



The Shifts

Cognitive models need to focus on central/ overarching/powerful/ ideas in the domain.

Chemists have some sort of "obsession" for topical approaches

Stoichiometry Kinetics Equilibrium Acid-Bases	Global warming Ozone layer Polymers Drugs	vs.	Structure/Properties Chemical Classification Chemical Synthesis

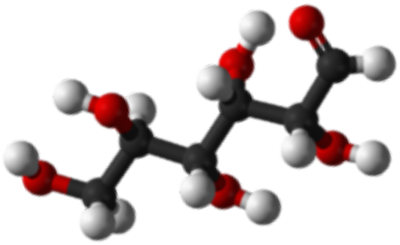
What they know → **How they think**

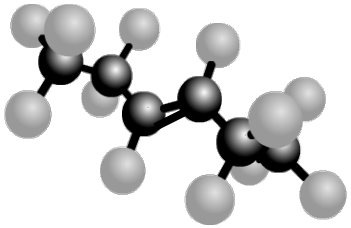
The Interest

Imagine that you were interested in exploring how people with different levels of expertise understand/think about/apply structure → properties relationships.

Glucose

$C_6H_{12}O_6$



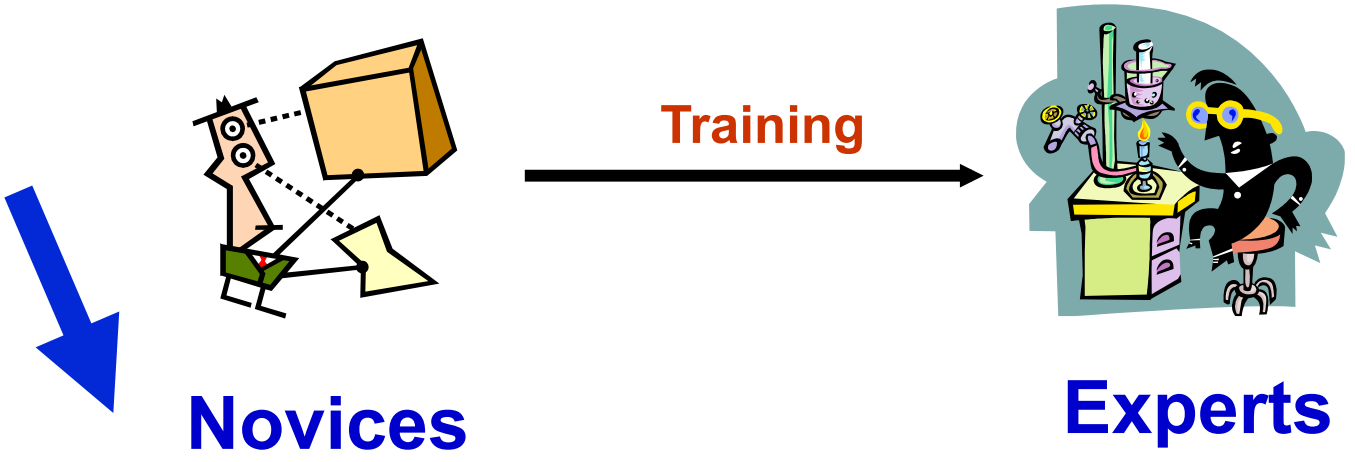


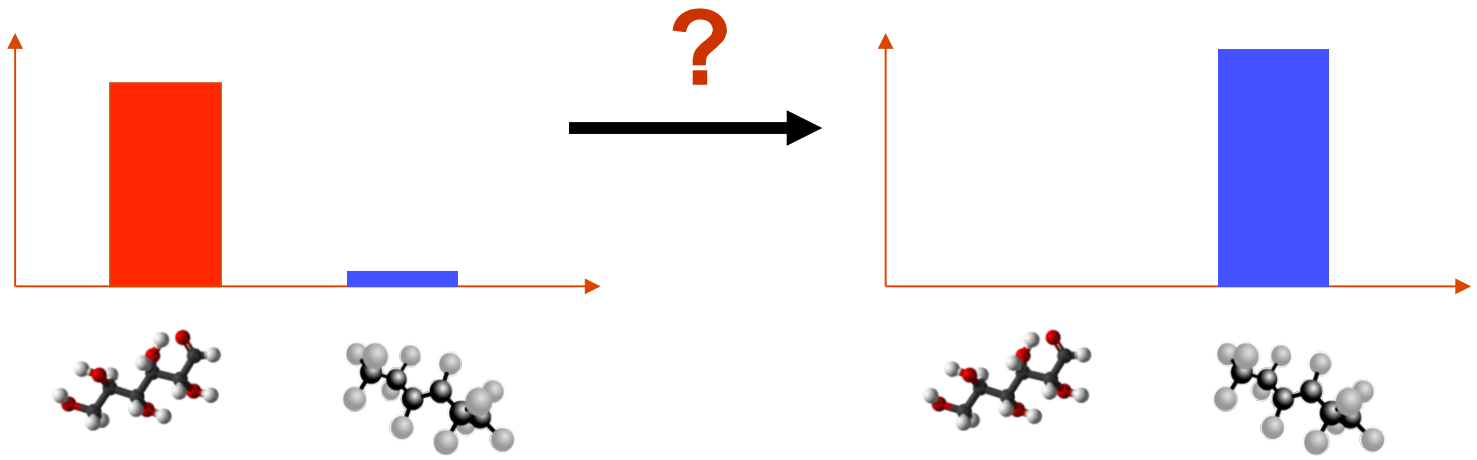
Hexene

C_6H_{12}

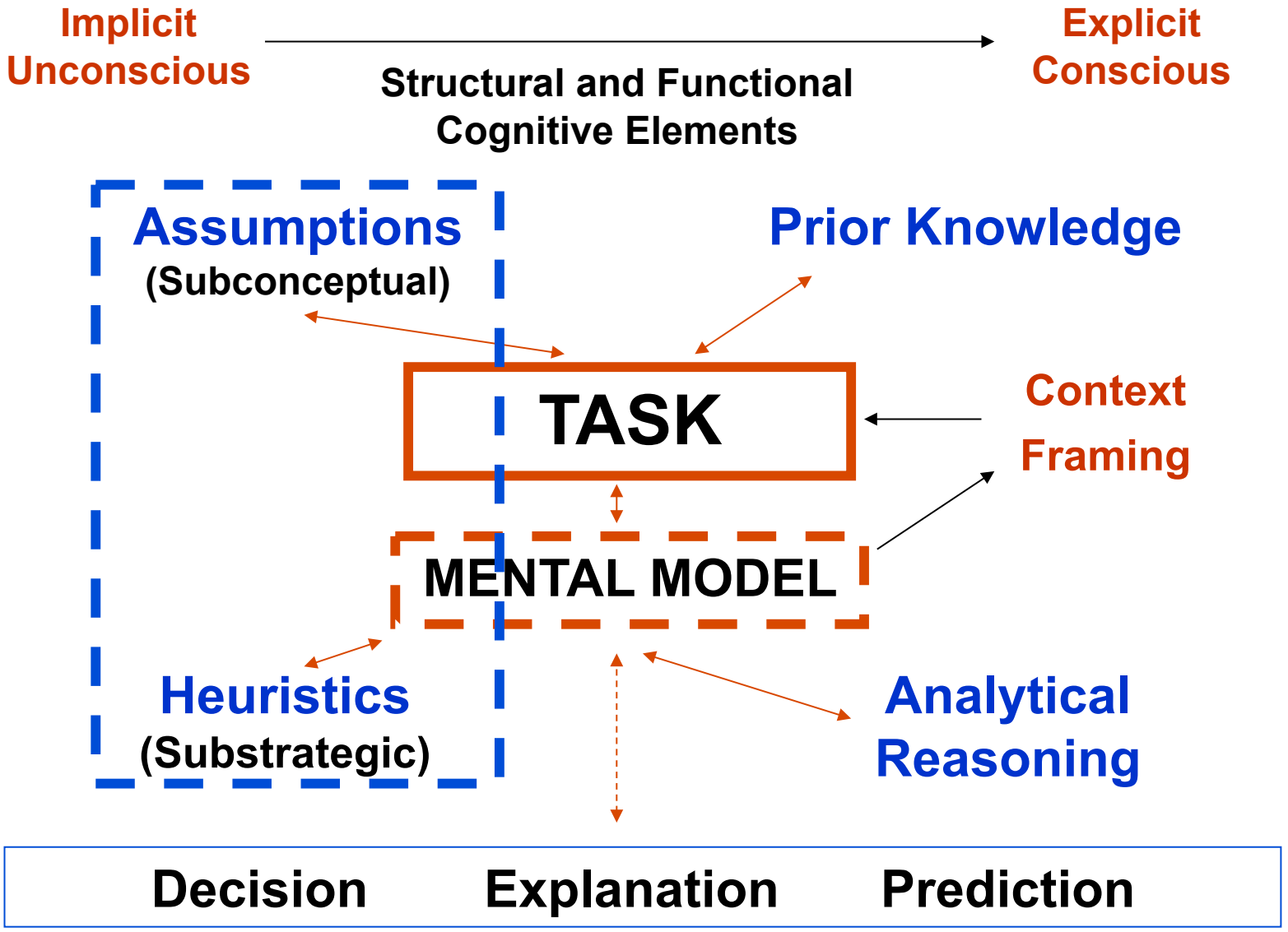
Which of these two molecules will generate more energy upon combustion?

The Challenge





Our Framework

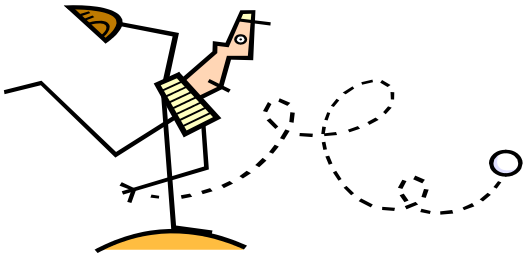


Our Work

GOAL: Identification and characterization of implicit assumptions and heuristics that constrain chemistry students' thinking.

Tasks that Demand Qualitative Reasoning

- Classification
- Prediction/Inference
- Comparison and Ranking
- Explanation

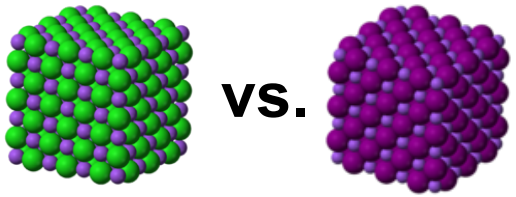


The Focus

HEURISTIC REASONING

TASKS

Comparison and Ranking



Heuristics?

Simple (preconscious) reasoning processes that reduce the effort associated with a task, particularly under conditions of limited time, knowledge, and computational power.

FAST
FRUGAL

ADAPTIVE
OR
ECOLOGICALLY
RATIONAL

DOMAIN-GENERAL but **TASK-SPECIFIC**

Heuristics

Do fires or tuberculosis cause more deaths in the US?

AVAILABILITY HEURISTIC

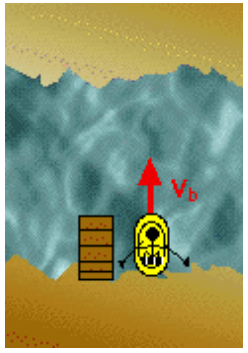
Which car brand is of better quality: Saab or Honda?

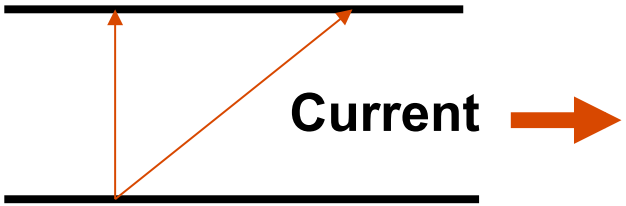
RECOGNITION HEURISTIC

Heuristics

What is happening?

LEXICOGRAPHIC HEURISTIC (More A → More B)





Day 1

Day 2

Crossing Time?

Frameworks

Heuristics reasoning has been described, modeled, and analyzed using different approaches:

Fast-and-Frugal Framework

Dual-Process Framework

Cognitive Resources Framework

Implicit Theories Framework

Fast-and-Frugal

Adaptive Toolbox

Human possess a repertoire of specialized heuristics that can solve specific tasks in specific environments.

They draw from:

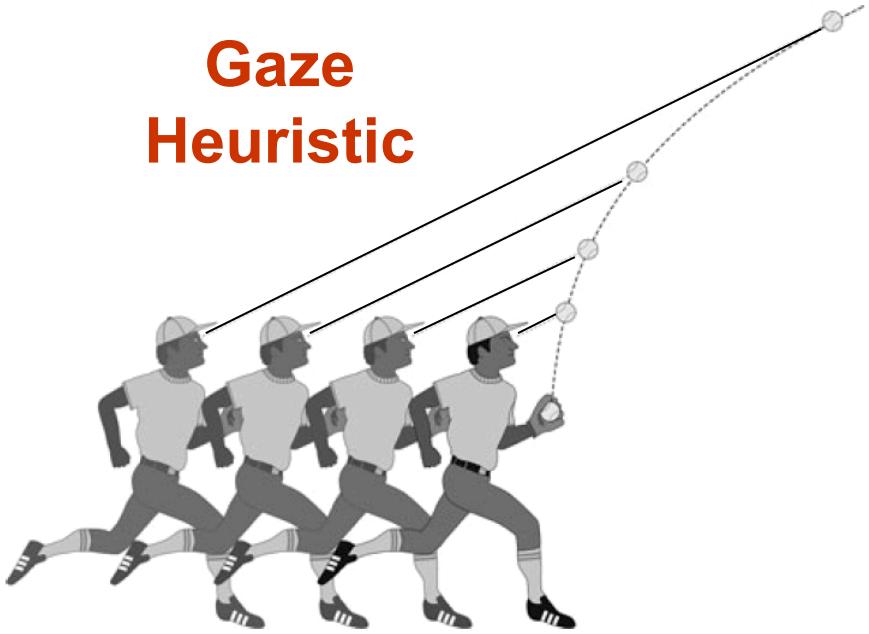
- **Core capacities (e.g., memory, vision);**
- **Environment structure (physical, social)**

P. M. Todd & G. Gigerenzer. ***Behavioral and Brain Sciences*** **23,** 727 (2000).

Fast-and-Frugal

How do we catch baseballs?

Gaze Heuristic



Reliance on implicit assumptions about the world

Dual-Process

Dual-process theories claim that we have two different modes of information processing:

Type 1 (Heuristic)	Type 2 (Analytical)
Unconscious	Conscious
Automatic	Controlled
Low Effort	High Effort
Rapid	Slow
Pragmatic, perceptual	Analytic, reflective
Independent of WMC	Limited by WMC
Default	Inhibitory

J. S. B. T. Evans. ***Annu. Rev. Psychol.*** **59,** 255 (2008).

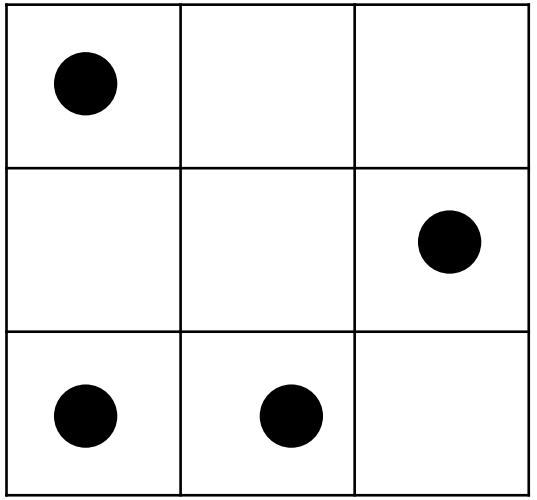
Dual-Process

Let's do some problems!

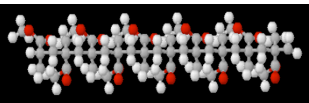
On the following slides I will show you some typical math word problem tasks.

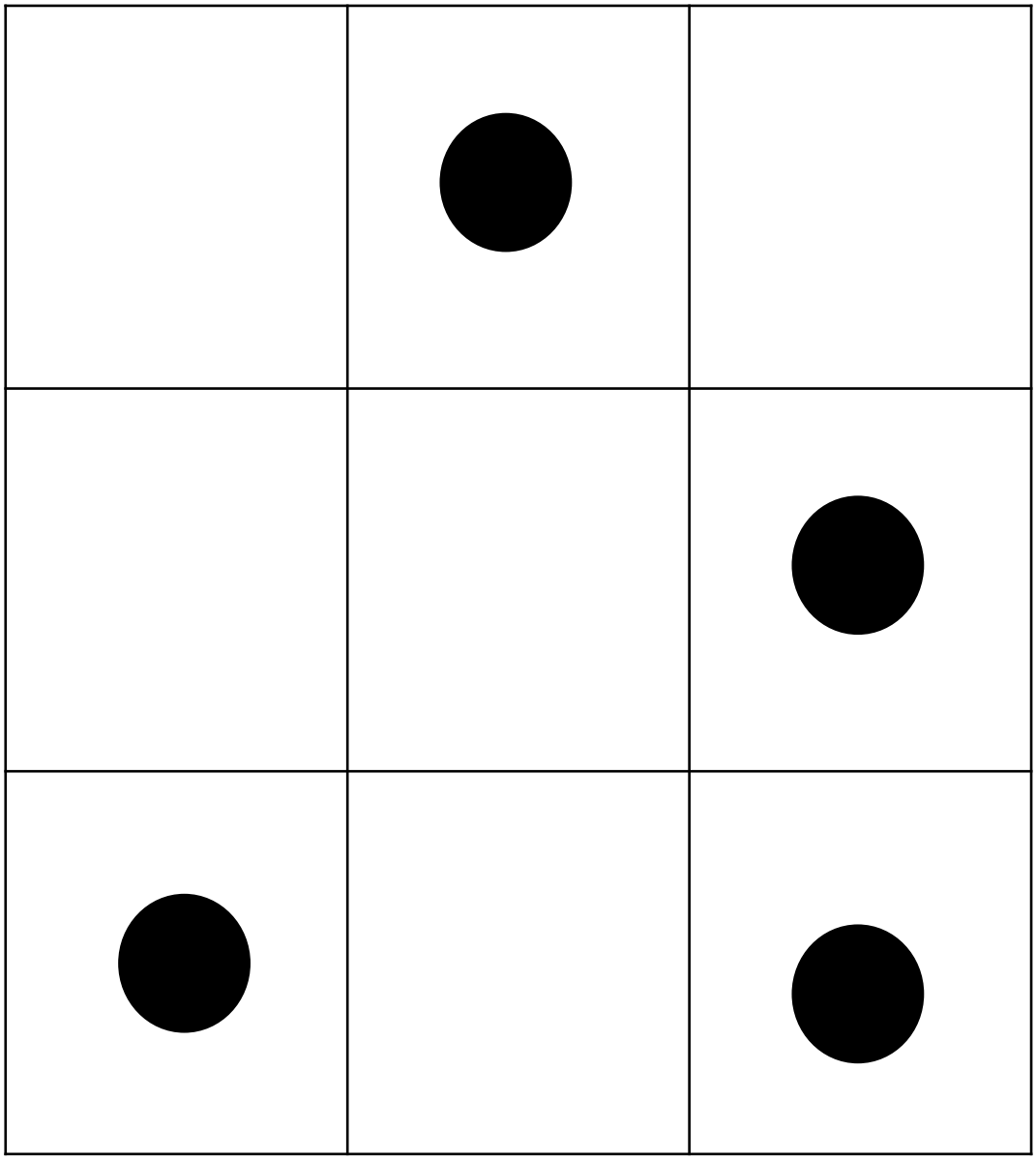
Before showing each problem, I will display a "dot matrix" like this for 1 s.

Then I will show the problem, give you 15 s to solve it, and ask you to write the numerical answer together with a drawing of the dot matrix.



Exploring Heuristic Reasoning





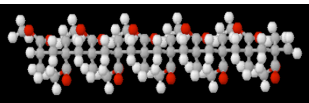
Erik and Tom buy boxes of pencils in the shop. All boxes are equally expensive, but Erik buys fewer boxes.

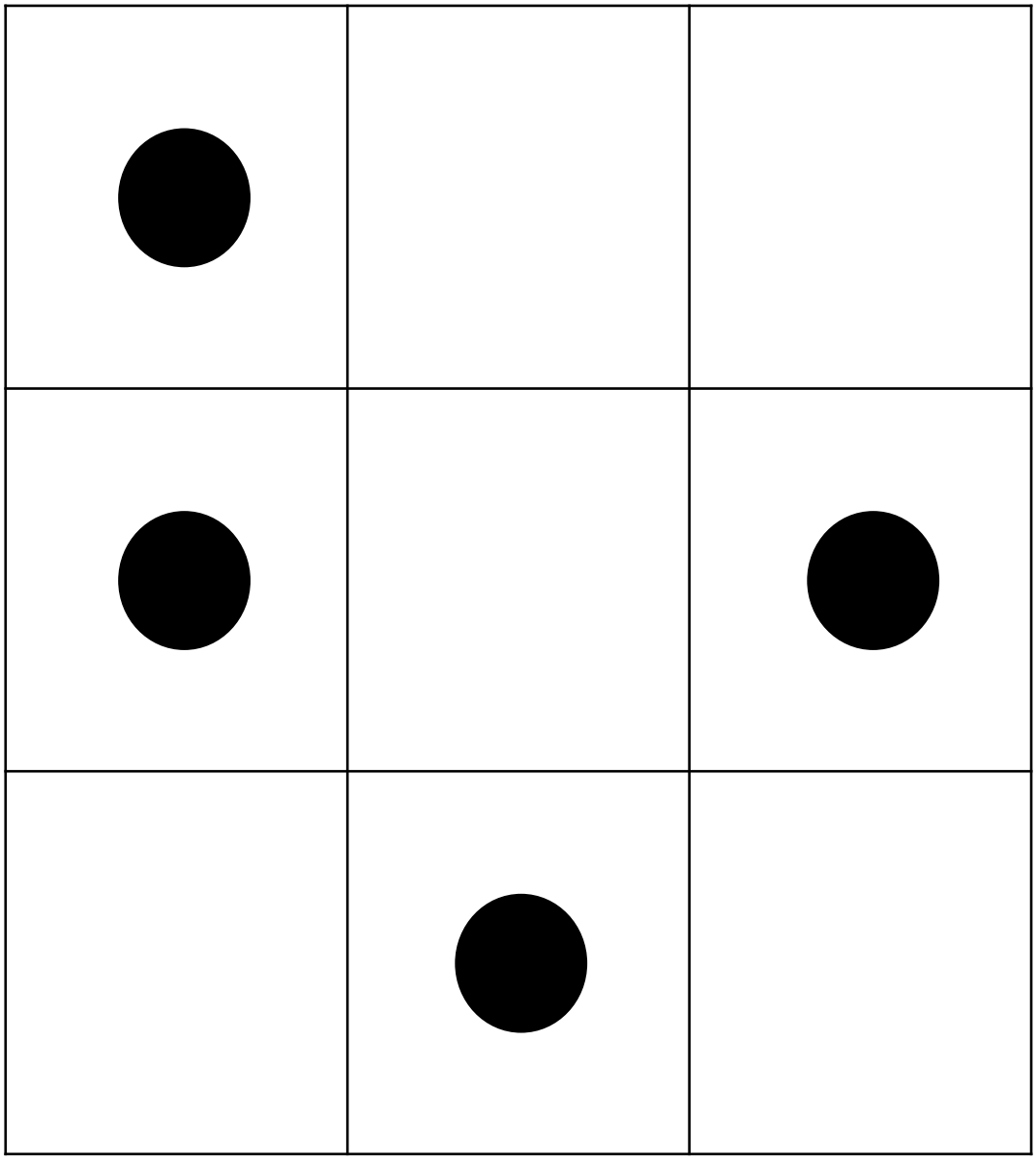
Erik buys 4 boxes of pencils, while Tom buys 8 boxes.

If Erik has to pay 24 dollars, how much does Tom have to pay?

Your Answer

Exploring Heuristic Reasoning





Ellen and Kim are running around a track. They run equally fast but Ellen started later.

When Ellen has run 5 laps, Kim has run 15 laps.

When Ellen has run 30 laps, how many has Kim run?

Your Answer

Decision Making

Analytical judgment and decision making requires the consideration of all of the available alternatives and cues for each alternative:

1. **Identifying all cues (piece of information);**
2. **Recalling and storing cue values;**
3. **Assessing the weights of each cue;**
4. **Integrating information for all alternatives;**
5. **Comparing all of the alternatives.**

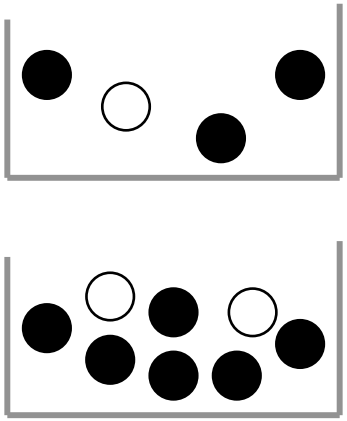
Shah & Oppenheimer. ***Psychological Bulletin***. **134**, 207 (2008).

Heuristics

Heuristic reasoning is based on strategies of **effort-reduction** and **simplification** in any of these areas:

1. Examining fewer cues;
2. Reducing the difficulty for retrieving and storing cue values;
3. Simplifying weighting principles for cues;
4. Integrating less information;
5. Examining fewer alternatives.

Do homicides or suicides cause more deaths in the US?



Our Investigation

Analysis of college chemistry students' use of heuristics when solving "comparison and ranking" tasks:

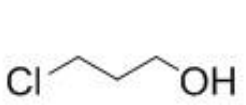
Explicit Composition Features

Which of the following substances is more soluble in water?

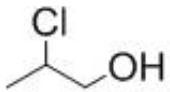
NaCl, MgO, BaO, NaBr

Explicit Composition and Structure Features

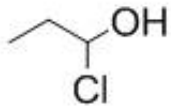
Which of the following substances is a stronger acid?



A



B



C

Methodology

The Subjects:

Science and Engineering majors enrolled in General Chemistry II.

Instruments:

- **Questionnaire (n = 414).**
- **½-hour interviews (34 → 25 F; 9 M)**

Maeyer & Talanquer. ***Science Education*** (Published online, 2010).

The Subjects:

Science majors enrolled in Organic Chemistry I.

Instruments:

- **½-hour interviews (20 → 11 F; 9 M)**

Analytical Reasoning

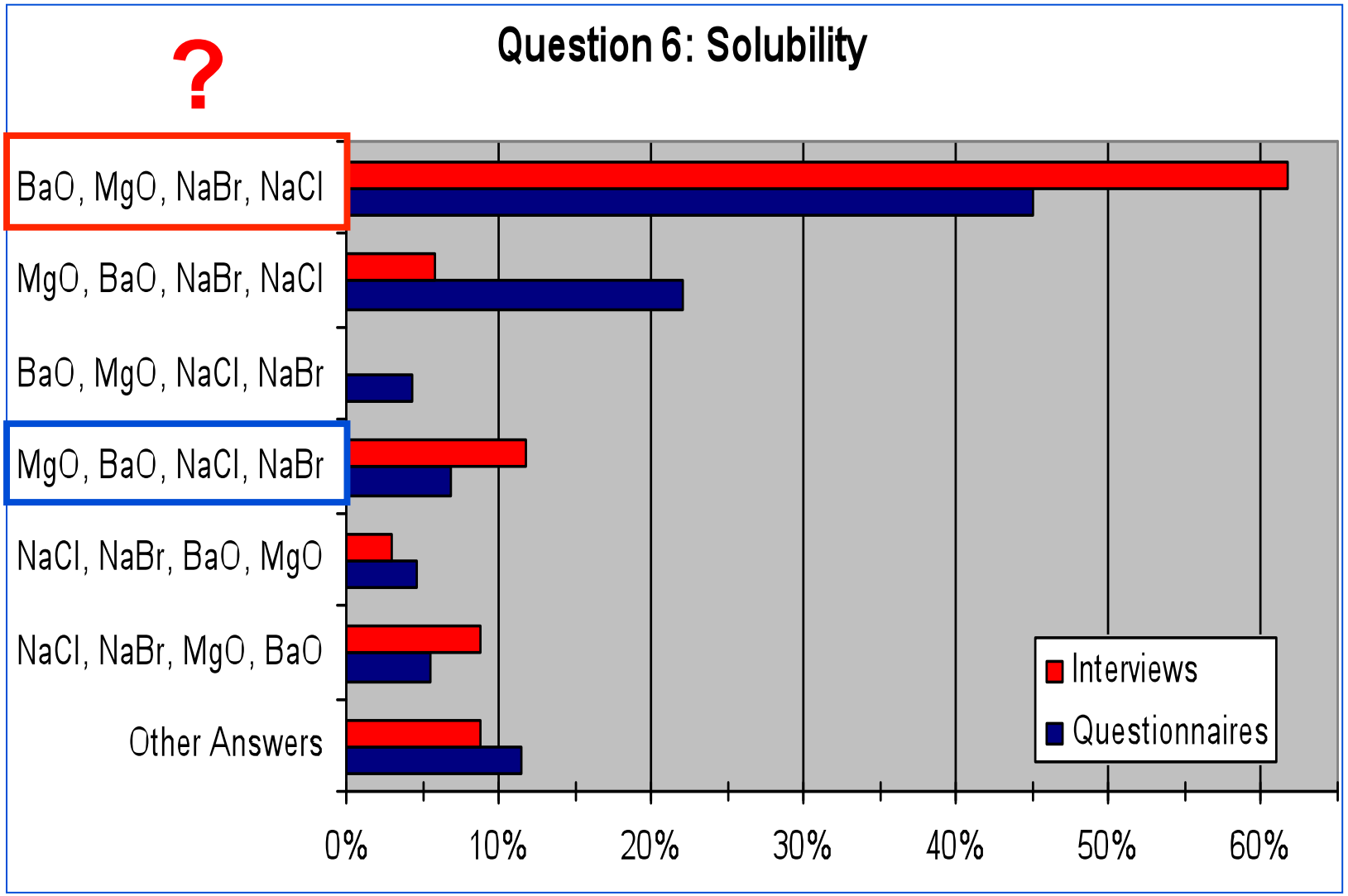
Arrange the following substances in order of increasing solubility:

NaCl, NaBr, MgO, BaO

1. **Identifying cues: Ionic, ion charge and size.**
2. **Recalling cue values: Na^+, Mg^{2+}, Cl^-, $r_{Cl^-} < r_{Br^-}$, …**
3. **Assessing cues: $F \sim q_1 q_2 / r^2$**
4. **Integrating information: MgO, BaO → NaCl, NaBr**
5. **Comparing options: MgO < BaO < NaCl < NaBr**

Exploring Heuristic Reasoning

Some Results



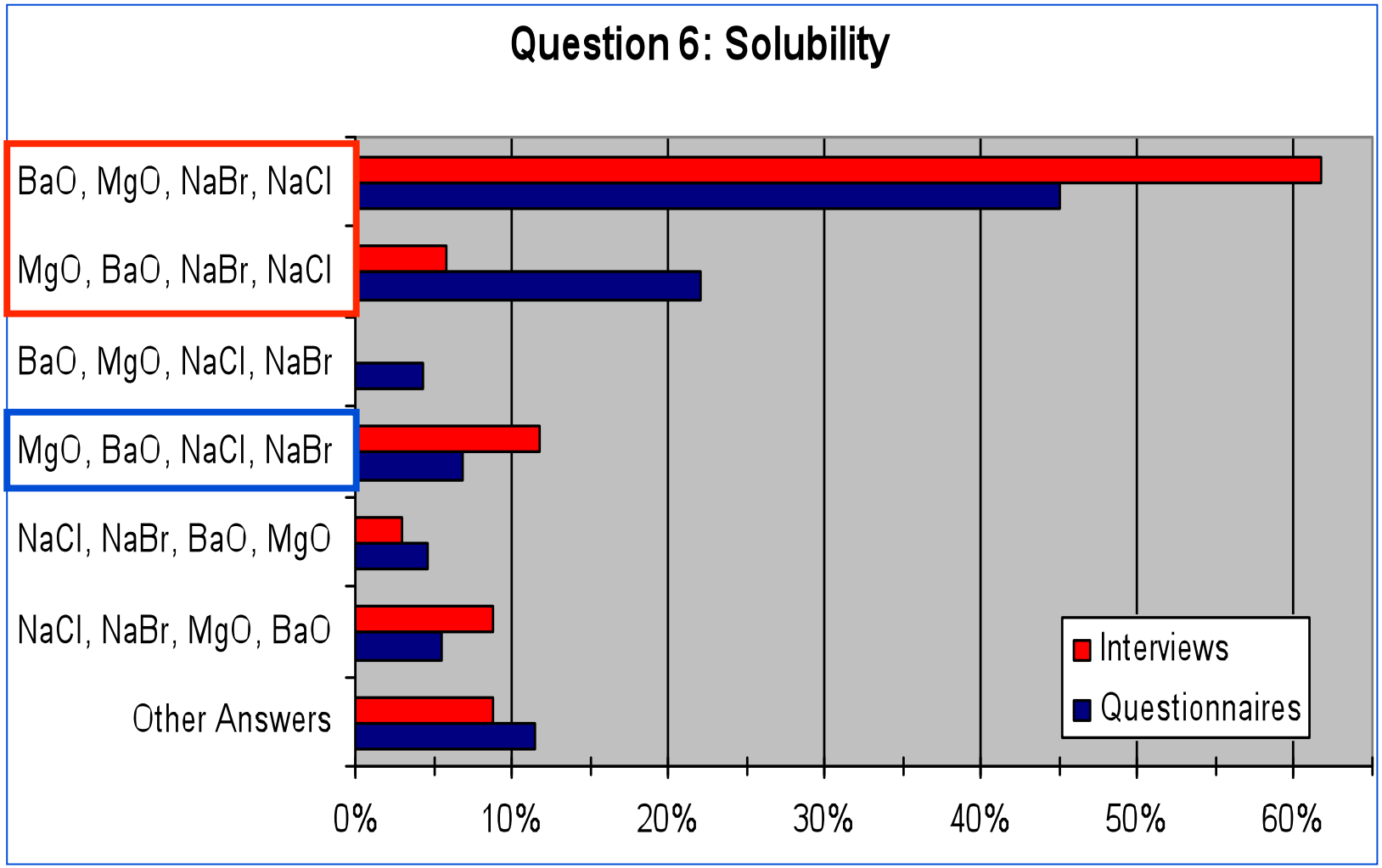
Some Heuristics

BaO < MgO < NaBr < NaCl ← Recognition

Recognition: If one object is recognized, then infer that the recognized object has the higher/lower value with respect to the criterion.

BaO < MgO < NaBr < NaCl ?

Some Heuristics



Some Heuristics

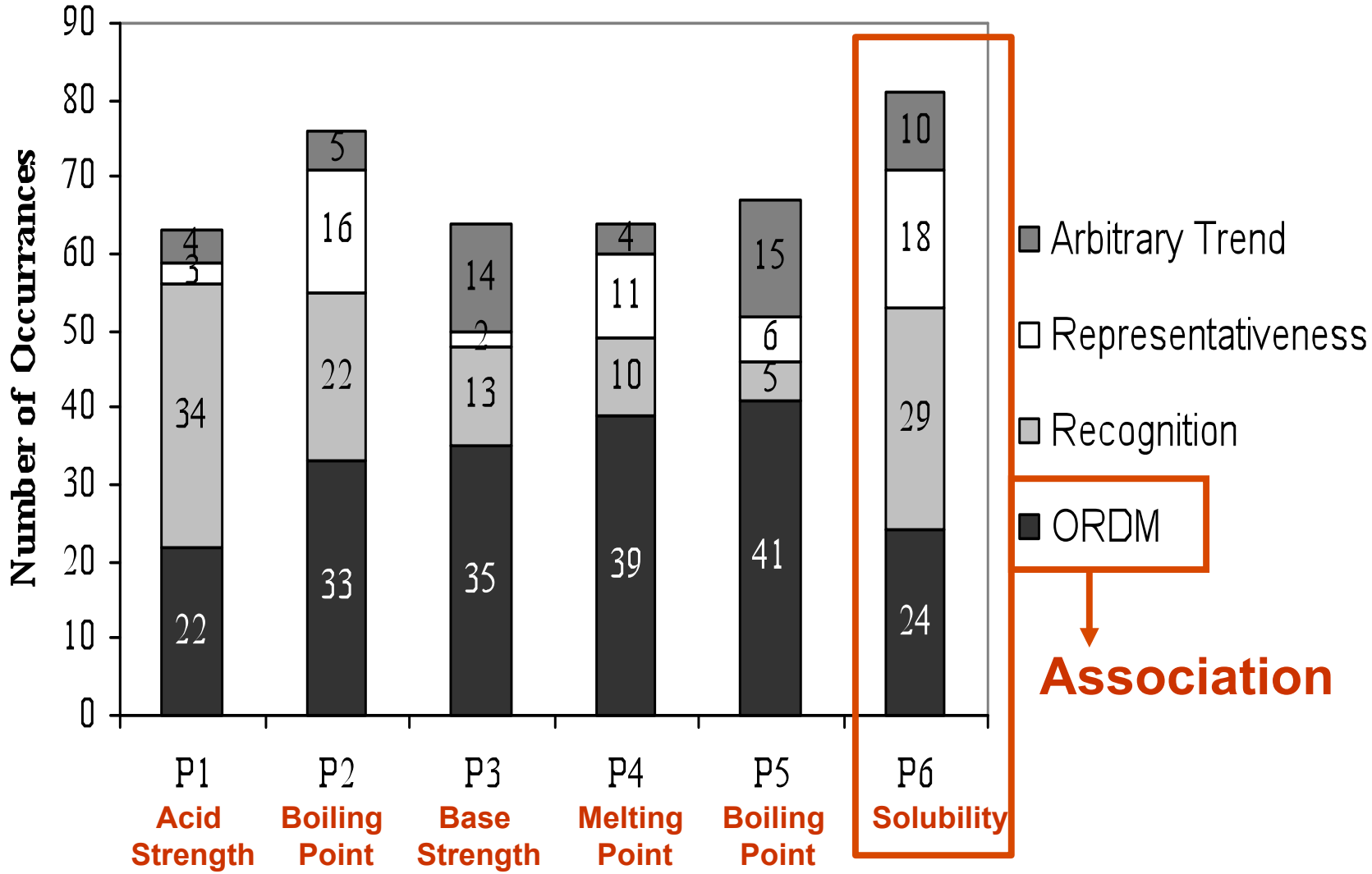
BaO < MgO < NaBr < NaCl ← Similarity

Similarity (Representativeness): Assume commonality between objects of similar appearance.

BaO < MgO < NaBr < NaCl ← Lexicographic (ORDM)

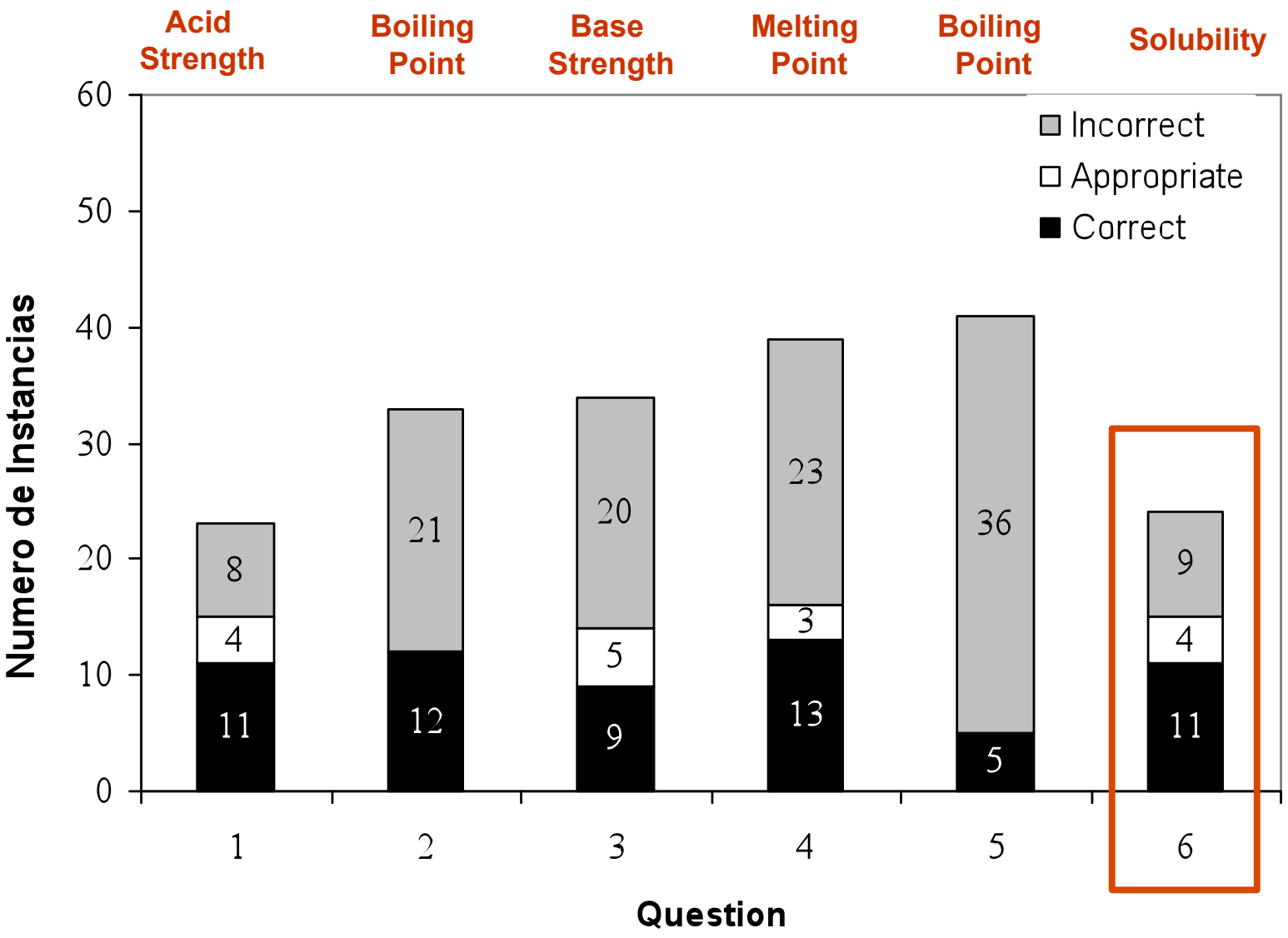
Lexicographic (One Reason Decision Making): Look for one differentiating cue (one at a time) that allow you to discriminate. Select the option with the highest or lowest value on the selected cue.

Heuristic Use

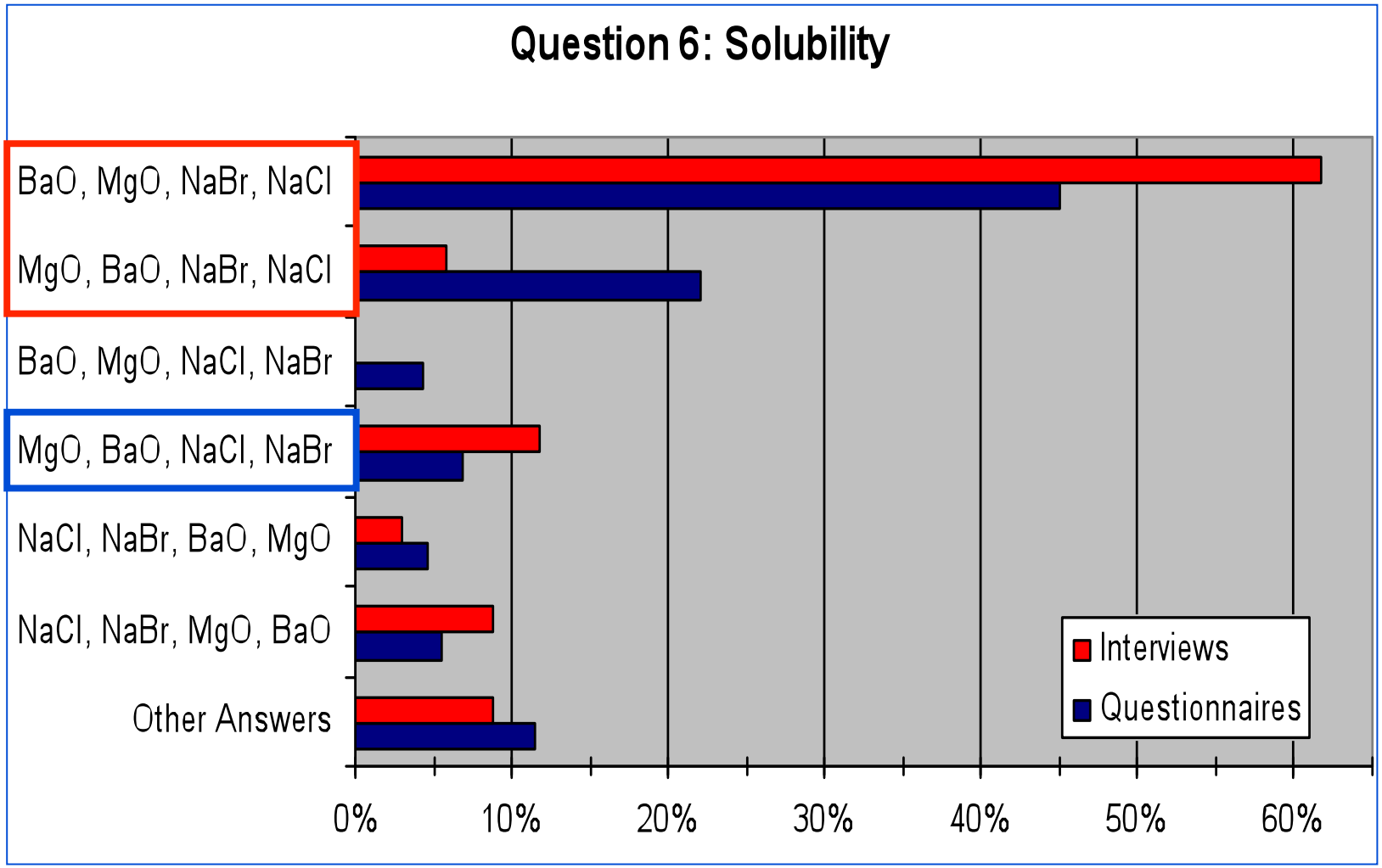


Exploring Heuristic Reasoning

Types of Associations



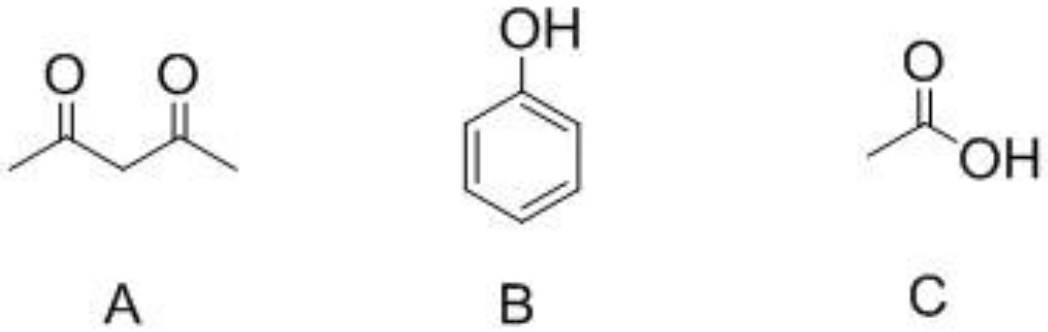
Some Heuristics



Structural Features

Ranking of substances based structural formulas relied on similar heuristics:

Strongest Acid?



Enriched Knowledge Base- Similar Reasoning Mechanisms

Functional Groups →

Recognition/Representativeness (Hybrids?)

Reduction

Saliency

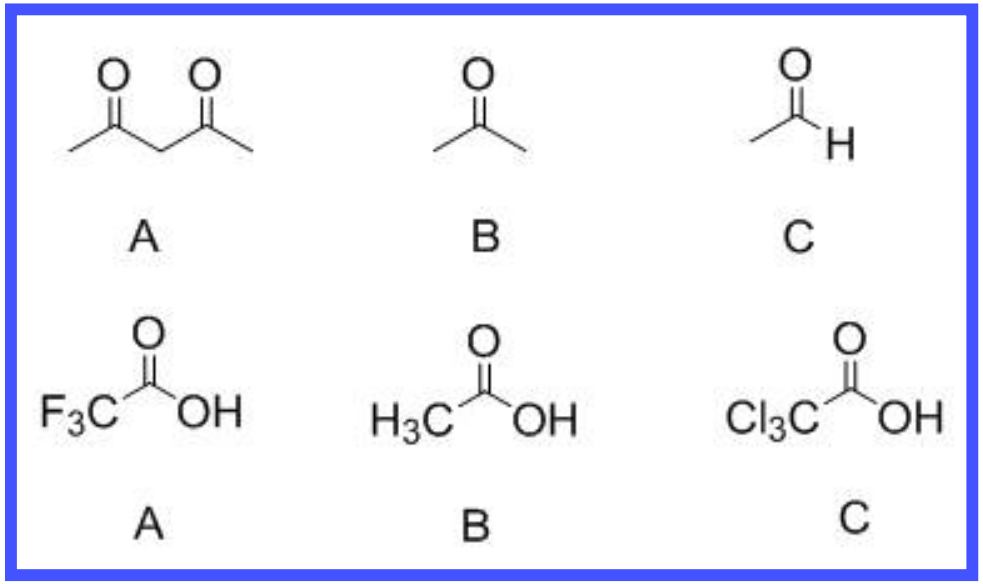
The nature of the most salient features of each task influenced both:

- **types of heuristics;**
- **cues,**

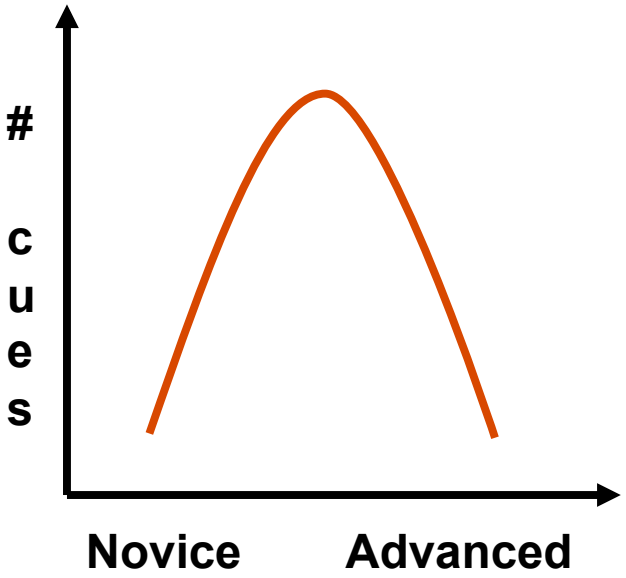
frequently used.

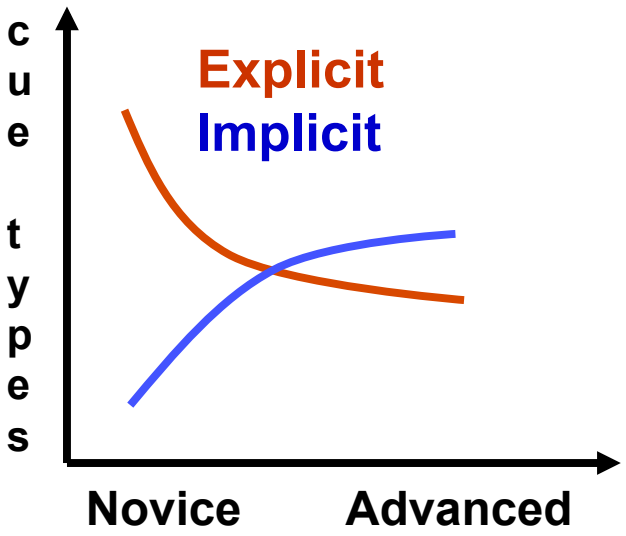
BOTTOM-UP
(representativeness, recognition; explicit cues)

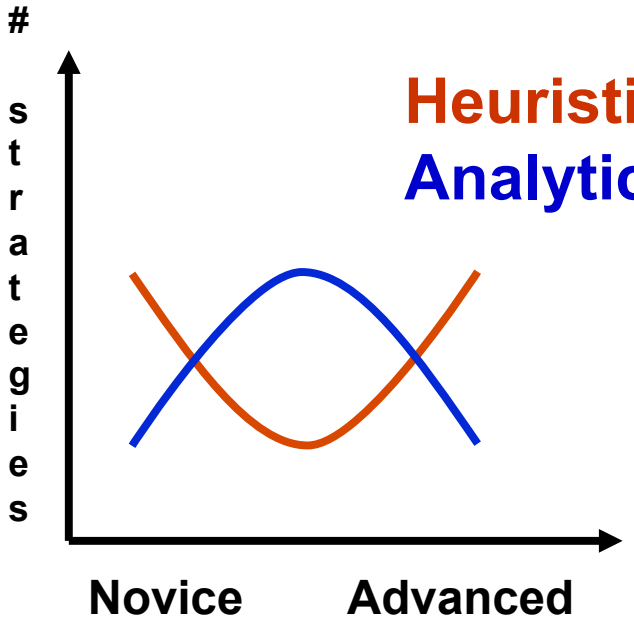
TOP-DOWN
(lexicographic; implicit cues)



Progression?



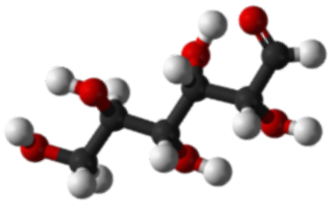


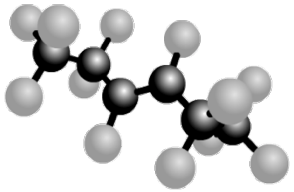


Why Then…?

Glucose

$C_6H_{12}O_6$

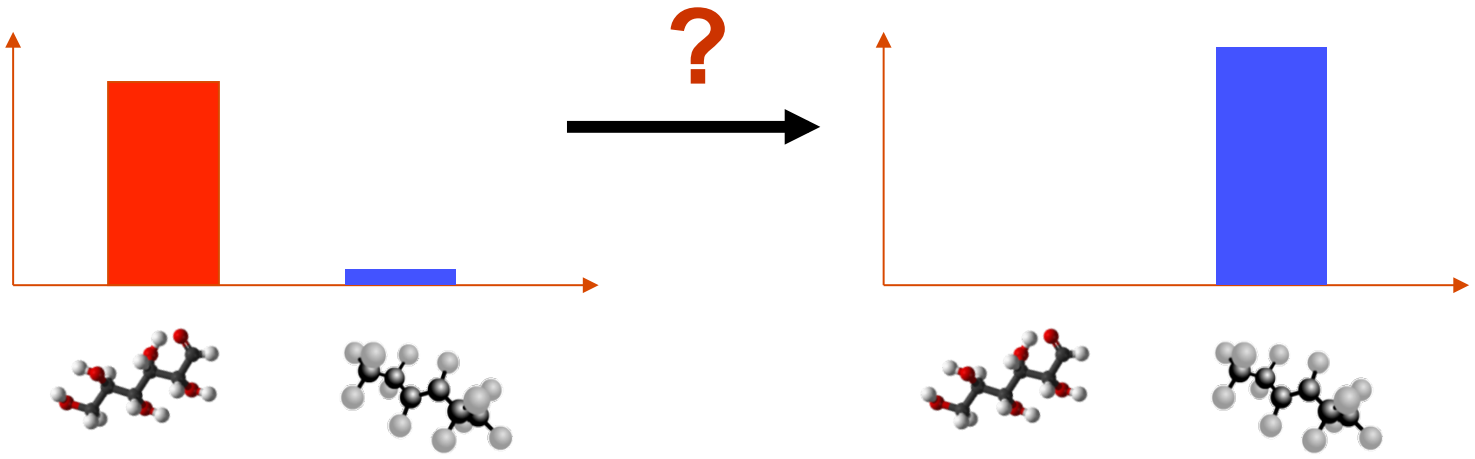




Hexene

C_6H_{12}

Which of these two molecules will generate more energy upon combustion?



Open Questions

Given what we know:

Instruction:

- How do we help students to better control or take advantage of heuristic reasoning?
- How do we better facilitate their identification of relevant cues in decision-making?

Assessment:

- How do we design assessments that differentiate between heuristic/analytical reasoning?

Exploring Heuristic Reasoning

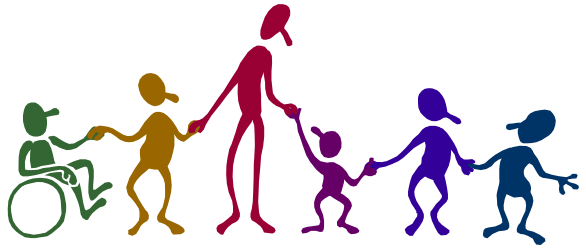
Acknowledgements

Graduate Students

Jenine Maeyer

Lakeisha McClary

Student Participants



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