Misconceptions that students bring with them into the chemistry classroom

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Our work

- **Research** on reasoning in chemistry
- **Development** of educational approaches that foster meaningful learning

Large number of students in a classroom

Central goal

- Summarize major **findings** from our **research on student reasoning in chemistry** that provide insights into the origin of many misconceptions

The evidence

Students come into our classrooms with a variety of pre-conceived ideas about the properties and behaviors of materials in our world

Some of these ideas differ from those accepted by the scientific community

- Preconceptions
- Misconceptions
- Alternative Conceptions

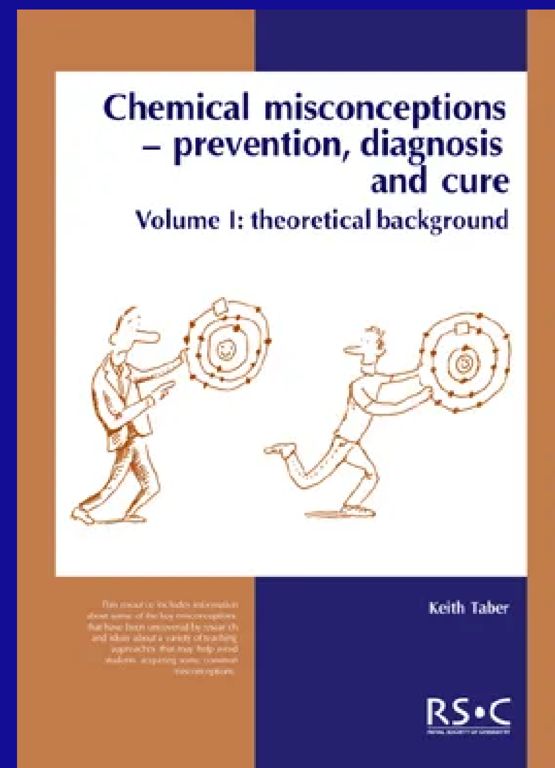
The research

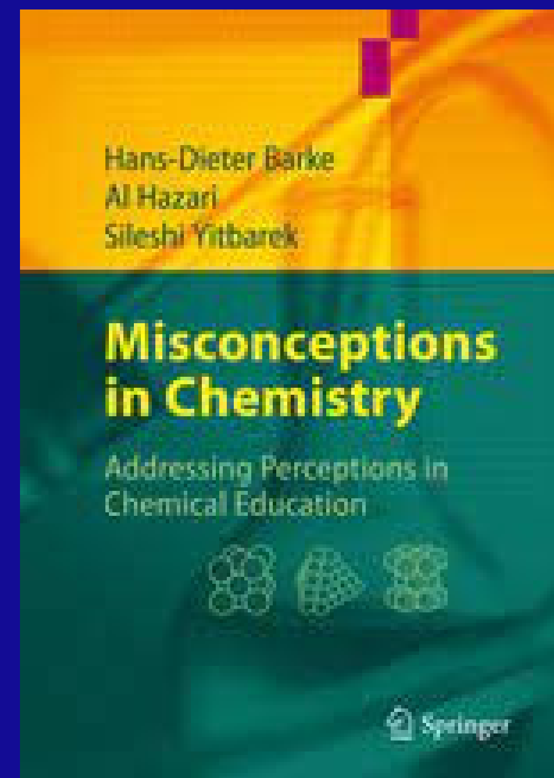
Many research studies in chemistry education have identfied and characterized students' misconceptions about a variety of chemical concepts and ideas

Why Some Students Don't Learn Chemistry

Chemical Misconceptions

Mary B. Nakhleh
Purdue University, West Lafayette, IN 47907





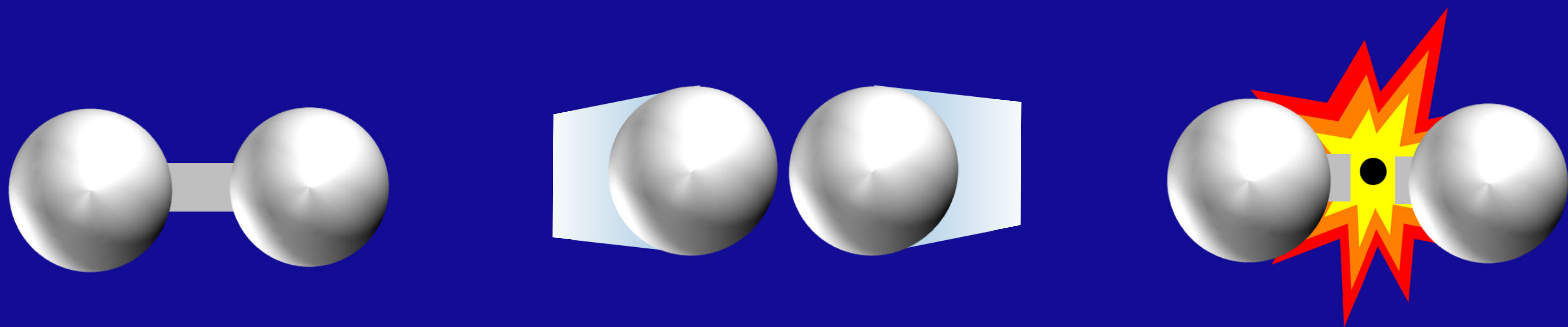
The conventional approach

Subject Matter (Content) → Teaching (Instructor) → Learning (Student)

Phase Transitions

The conventional approach

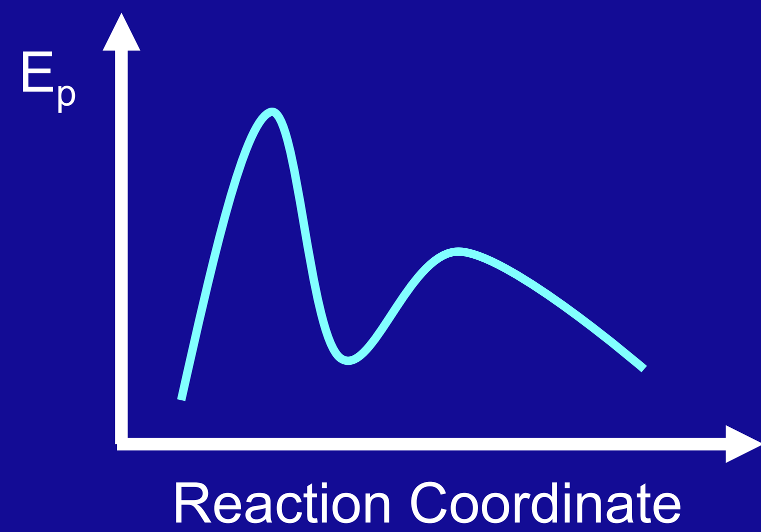
Subject Matter (Content) → Teaching (Instructor) → Learning (Student)

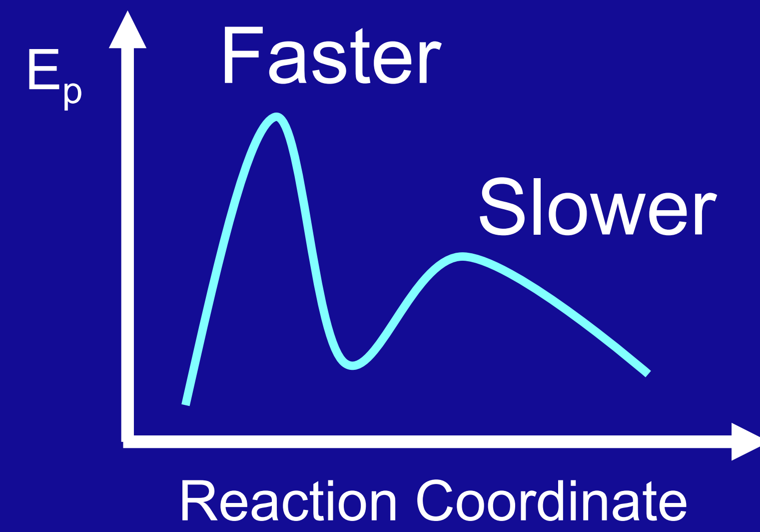


Bond Energy

The conventional approach

Subject Matter (Content) → Teaching (Instructor) → Learning (Student)





Reaction Rate

Long list

Chemical bonds release energy when broken
Chemical reaction stop at equilibrium
Nuclear force is equally divided among each electron
Molecules in gases move faster than in liquids
Atoms can be seen with a microscope
Water decomposes when boiling
Electron shells are thin and hard
All chemical changes are irreversible
Atoms have different colors
Total mass decreases when a substance burns
Ionic compounds are comprised of molecules

Why and how misconceptions emerge?

Our research

Our studies have shown that many misconceptions emerge from the application of implicit ways of thinking:

ASSUMPTIONS

HEURISTICS

Talanquer. *J. Chem. Ed.* 83, 811 (2006).

Talanquer. *Concepts of Matter in Education.* 19,1419 (2013).

Assumptions

Implicit beliefs about objects and events

How do you explain it?

CONTINUITY COHERENCE

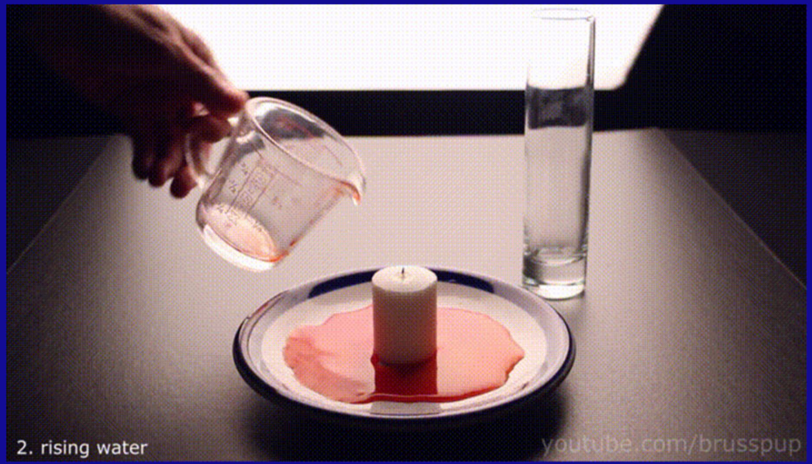
PERSISTENCE

Inferences

Why do birds fly in V-patterns?

Why do plants turn towards the sunlight?

What makes the feathers colored?



Why does water rise?

Inferences

Maeyer & Talanquer. *J. Res. Sci. Teach.* 50, 748 (2013).
Talanquer. *J. Chem. Educ*. 90, 1419 (2013).
Talanquer. *J. Chem. Educ*. 92, 3 (2015).

The following major assumptions often guide and constrain students' reasoning about chemical entities and phenomena:

Inherence

Homogeneity

Additivity

Centralized Causality

Teleology

Dynamic constructions

Pieces of Knowledge

Assumptions

Heuristics

Talanquer. *J. Chem. Ed.* 92, 3 (2015).

Heisterkamp & Talanquer. *J. Chem. Educ*. 92, 1988 (2015).

Assumptions: Structure ←→ Properties

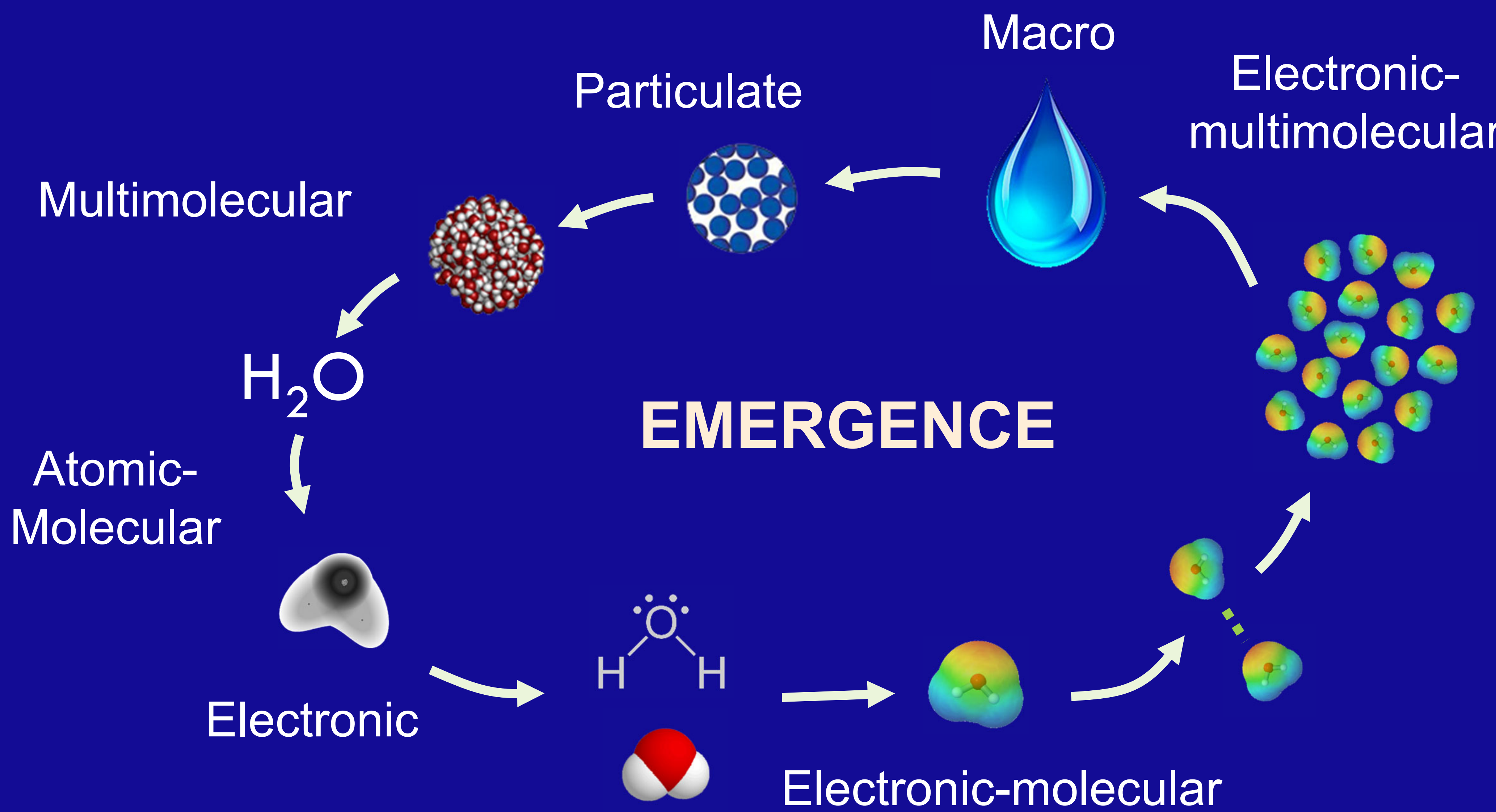
Why are they multicolored?
How do you explain it?

Common Assumptions

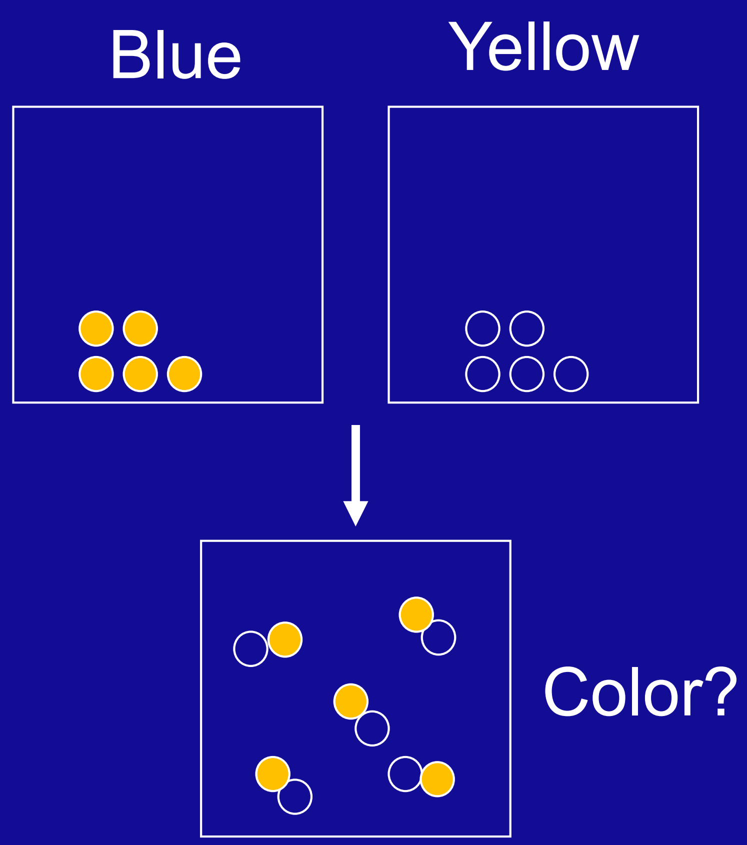
The subcomponents of matter have the same qualitative properties as macroscopic objects — **Inherence**

The properties of objects result from the weighted average of the properties of its individual components — **Additivity**

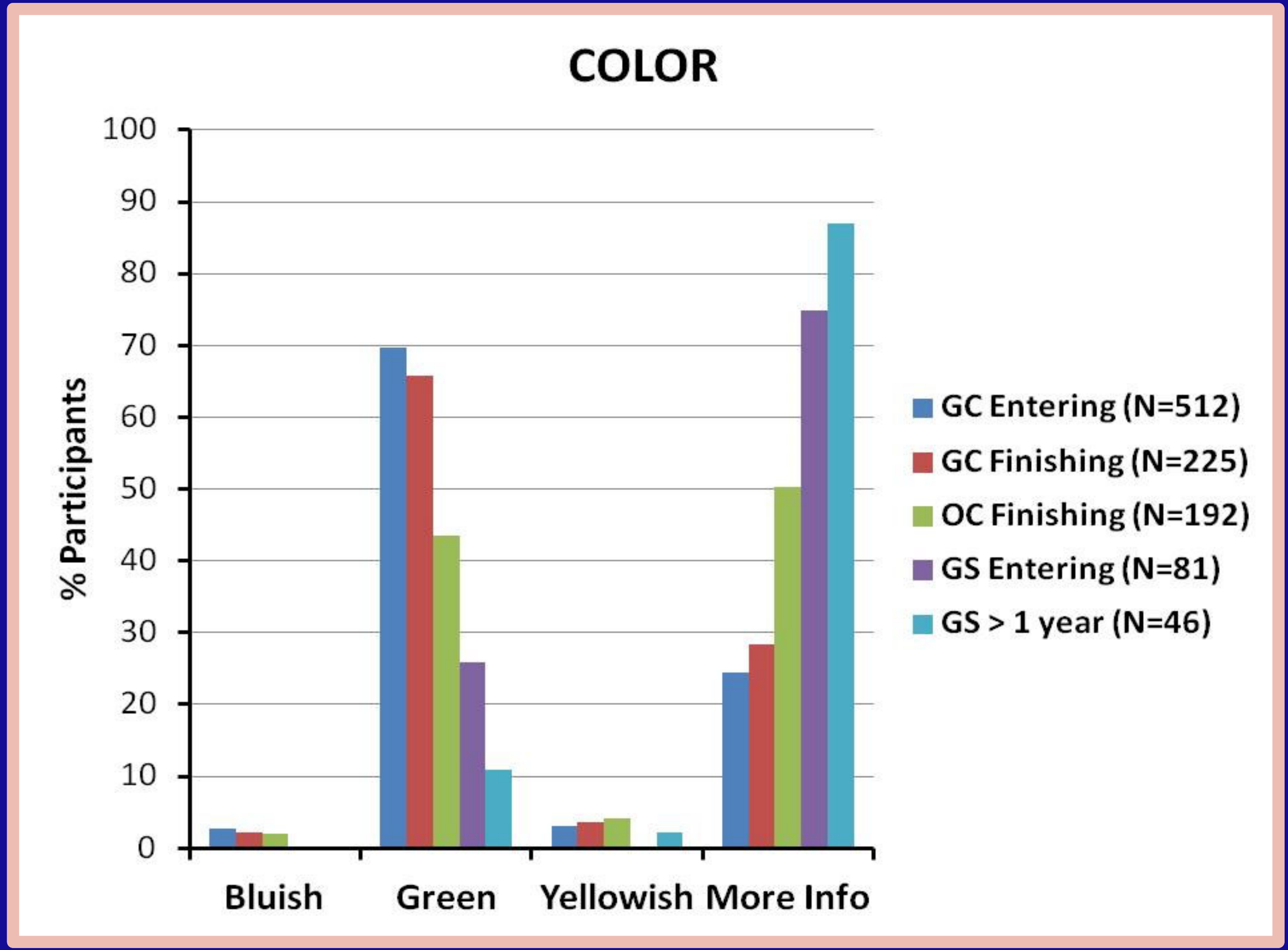
Targeted Reasoning



Inherence/Additivity



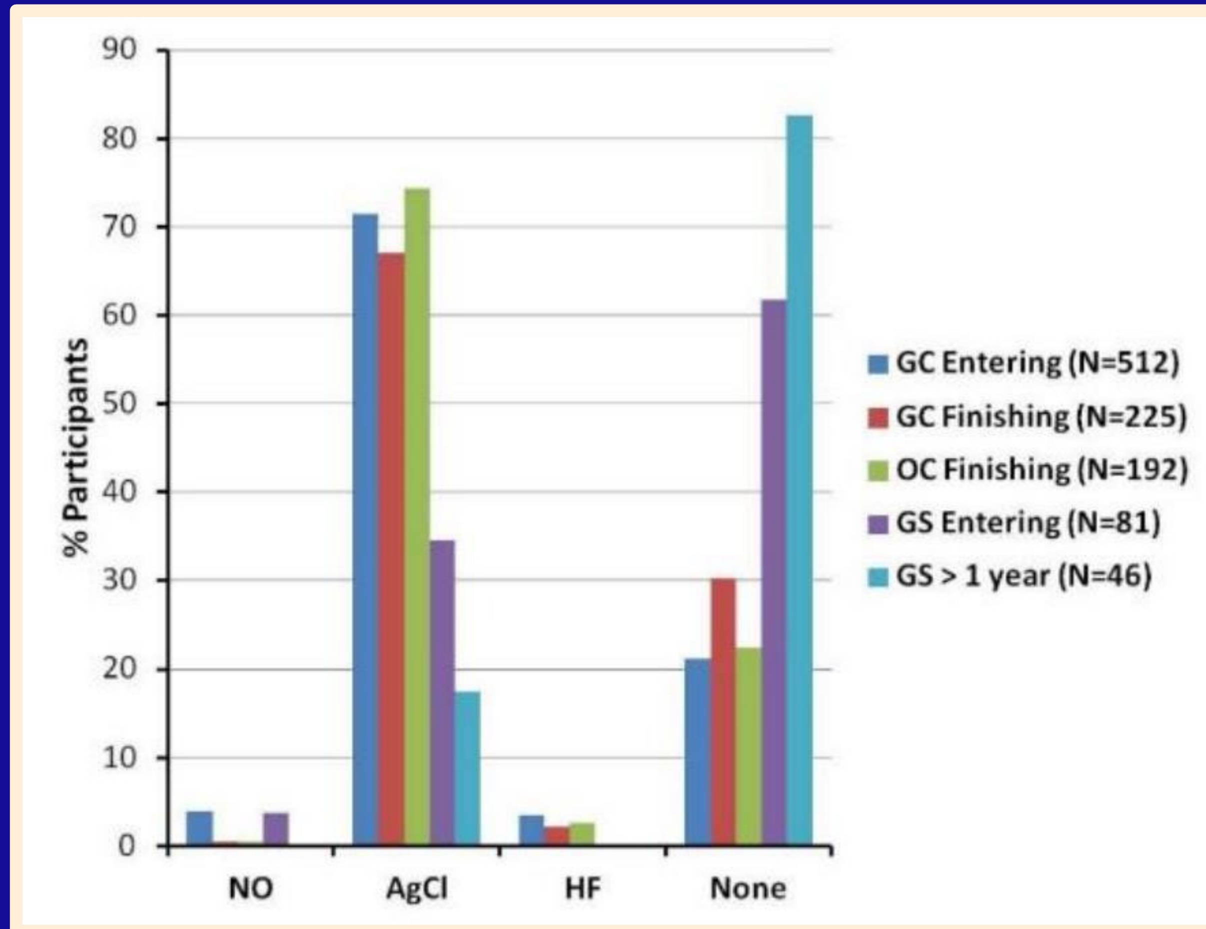
Talanquer. *Sci. Ed.* 92, 96 (2008).



Inherence/Additivity

Shiny & Malleable:
NO, AgCl, HF, None?

What would you expect?



Talanquer. *Concepts of Matter in Education.* 19,1419 (2013).

Assumptions: Composition ←→ Behavior

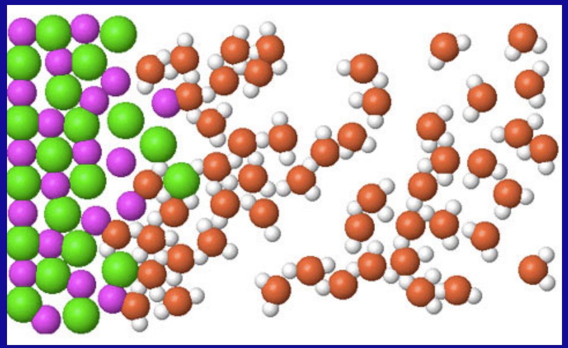
Have you ever seen birds flying like this? How do you explain it?

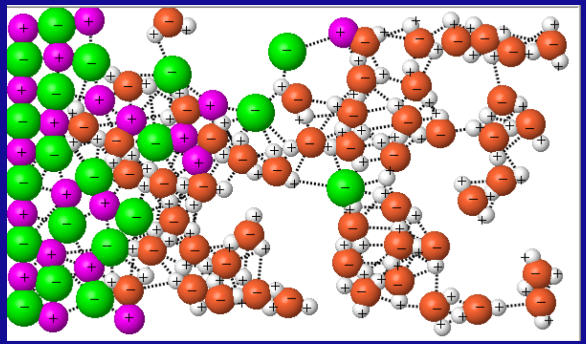
Common Assumptions

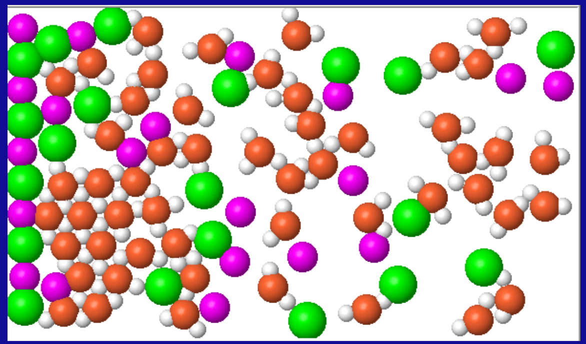
- Processes are driven by active agents that act on or are hindered by more passive agents — **Centralized Causality**
- The directionality of processes is determined by the goals or intentions of active agents — **Teleology**

Targeted Reasoning

Biased Random Dynamics





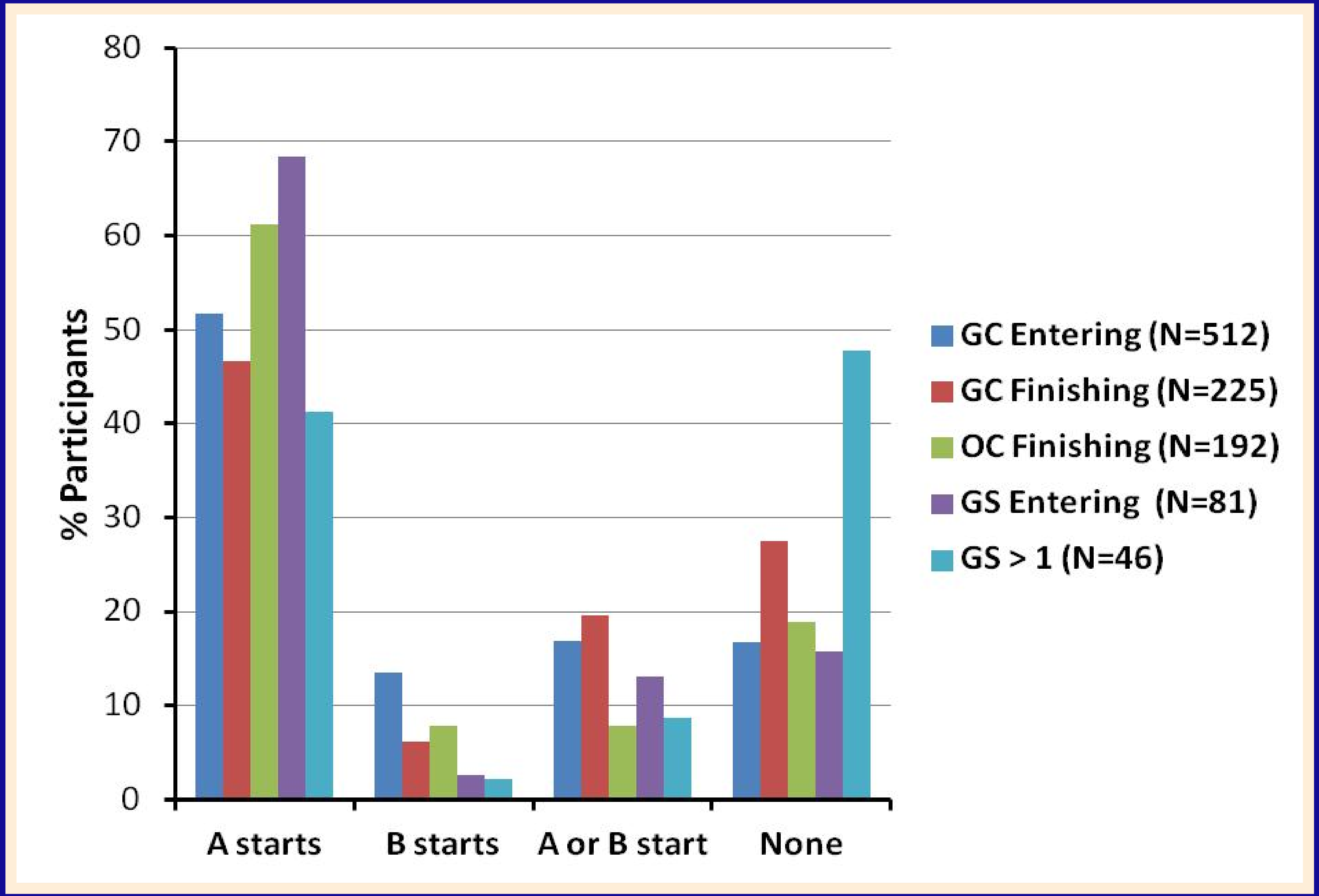


Energy vs. Entropy

Centralized Causality/Teleology

A is more (XXX) than B. When the substances are mixed,

How does the reaction start?



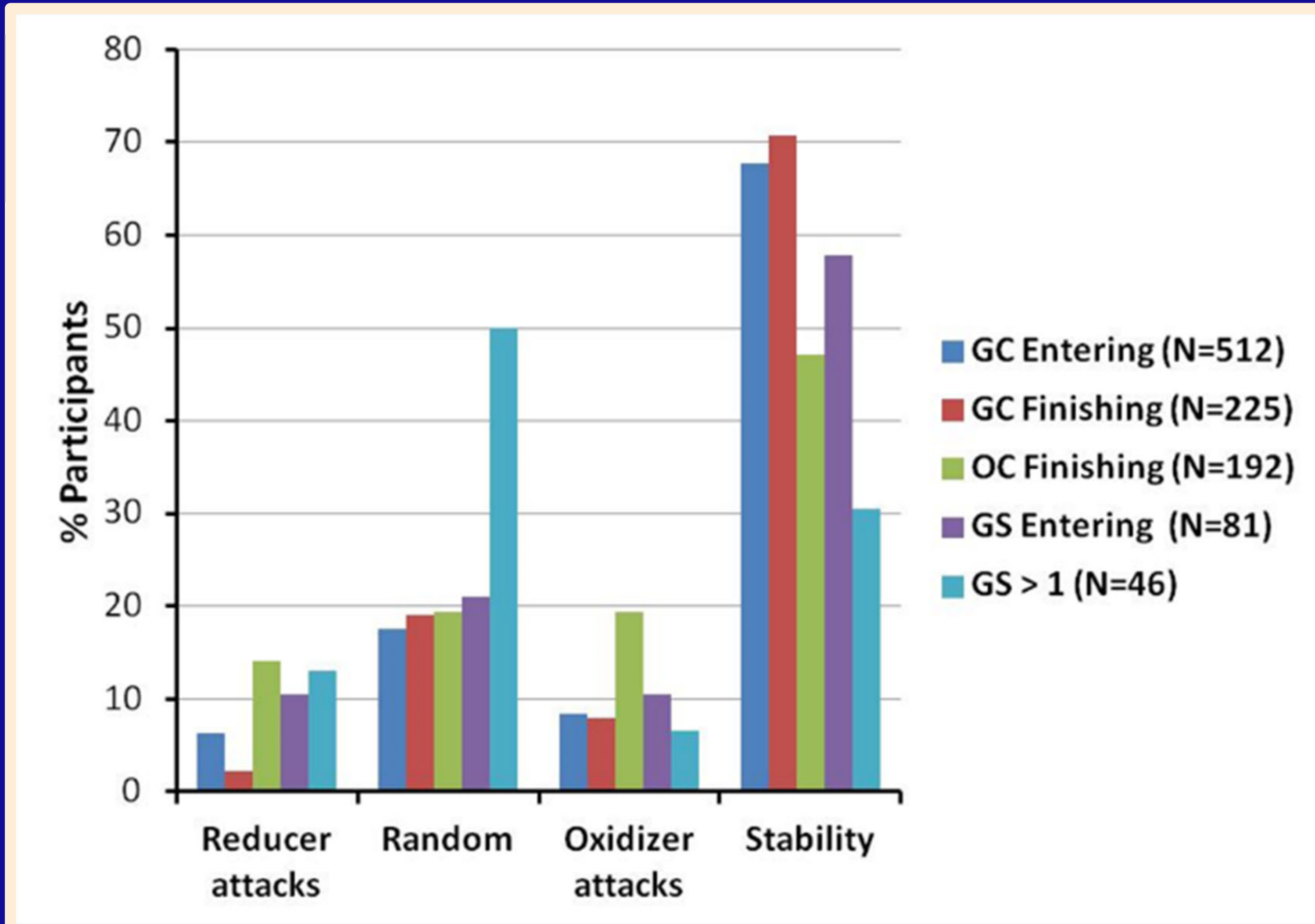
Talanquer. *Chem. Educ. Res. Pract*. 39 (2017).

Centralized Causality/Teleology

Red + Ox → C

Electrons are transferred

Why does the reaction happen?

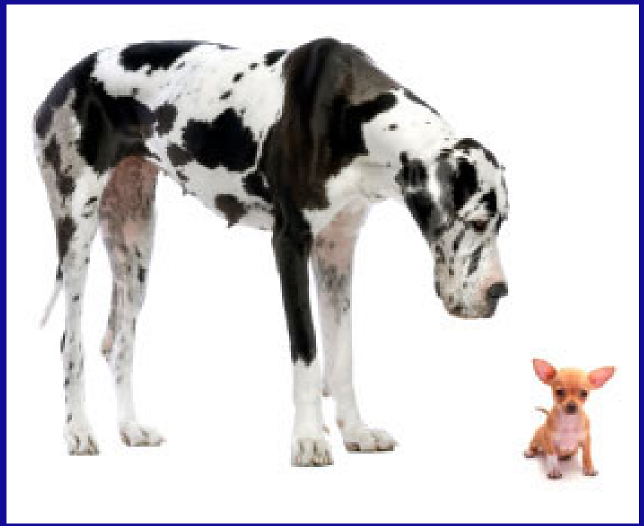


Talanquer. *J. Chem. Educ*. 90, 1419 (2013).

Student Reasoning

Students often apply
“CENTRALIZED CAUSALITY/TELEOLOGY”
in the analysis of systems where they perceive interactions between asymmetric objects.

Larger
Heavier
Stronger
Larger Amount



Making decisions

Our research shows that students often rely on reasoning heuristics (short-cuts) that reduce cognitive load in decision making

Reasoning Heuristics

Maeyer & Talanquer. *Sci. Ed.* 94, 963 (2010).

McClary & Talanquer. *Int. J. Sci. Educ. 33*,1433 (2011).

Talanquer. *J. Chem. Ed.* 91, 1091 (2014).

Heuristics

We often rely on fast and frugal mental strategies (heuristics) to make decisions and build inferences

What milk would you buy?

Who would you trust?

What to choose?

Heuristic Reasoning

When making decisions, our mind often:

1. Focuses on the most **SALIENT** differentiating feature;
2. If possible, **ASSOCIATES** (based on implicit assumptions) this feature with the targeted quantity;
3. Unconsciously, **SUBSTITUTES** one difficult question by a simpler one.

Heuristic 1 : Recognition

Which substance is more soluble in water?

Potassium Iodide

KI

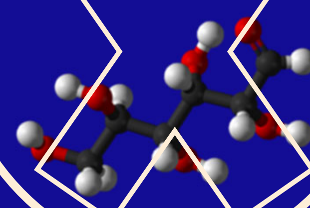
Sodium Chloride

NaCl

Which generates more energy upon combustion?

Glucose

$C_6H_{12}O_6$



Hexane

C_6H_{14}

Maeyer & Talanquer. *Science Education* 94, 963 (2010).

Recognition

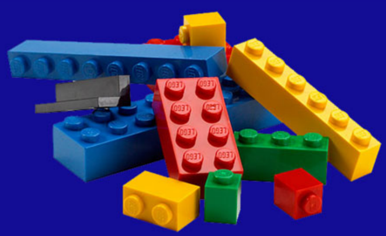
HEURISTIC RULE

If an option is recognized that exhibits the property under evaluation, place it at the top or bottom of the ranking.

Sodium Chloride

Heuristic reasoning

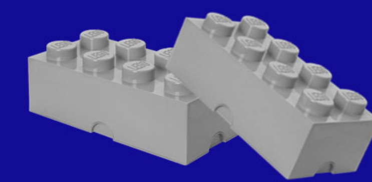
Our investigations have elicited the pervasive use of three main heuristics by students when making decisions in chemical contexts



RECOGNITION

SIMILARITY

ONE-REASON DECISION MAKING



Maeyer & Talanquer. *Sci. Ed.* 94, 963 (2010).

McClary & Talanquer. *Int. J. Sci. Ed.* 33, 1433 (2011).

Talanquer. *J. Chem. Ed.* 91, 1091 (2014).

How do you explain It?

OR

CH_4

Natural Gas

71%

Camping Burner

54%

CH_4O

Methyl Alcohol

The challenges

Centralized Causality

Teleology

Additivity

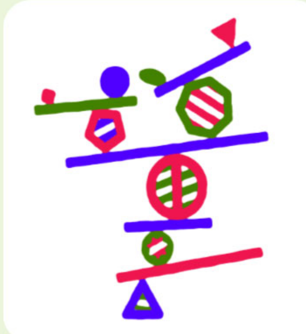
Inherence

Homogeneity

Heuristic Reasoning

Random Biased

Interaction



Emergence

Variability

Chemical Thinking

Talanquer. *J. Chem. Educ*. 92, 3 (2015).

Talanquer. *Chem. Educ. Res. Pract*. 39 (2017).

What to do?

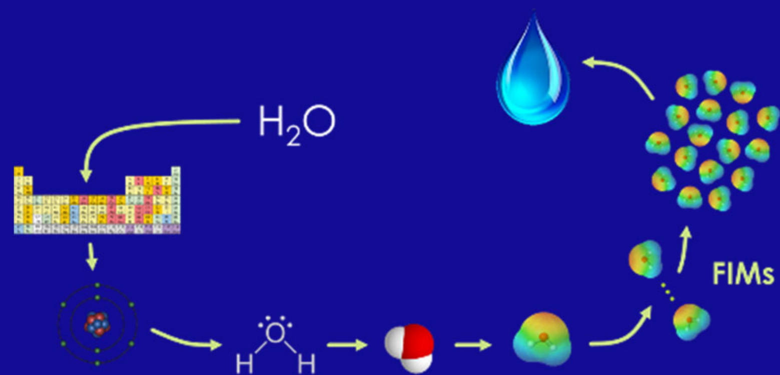
Beyond content knowledge

Chemistry is more than a body of knowledge

Way of Knowing

Way of Thinking

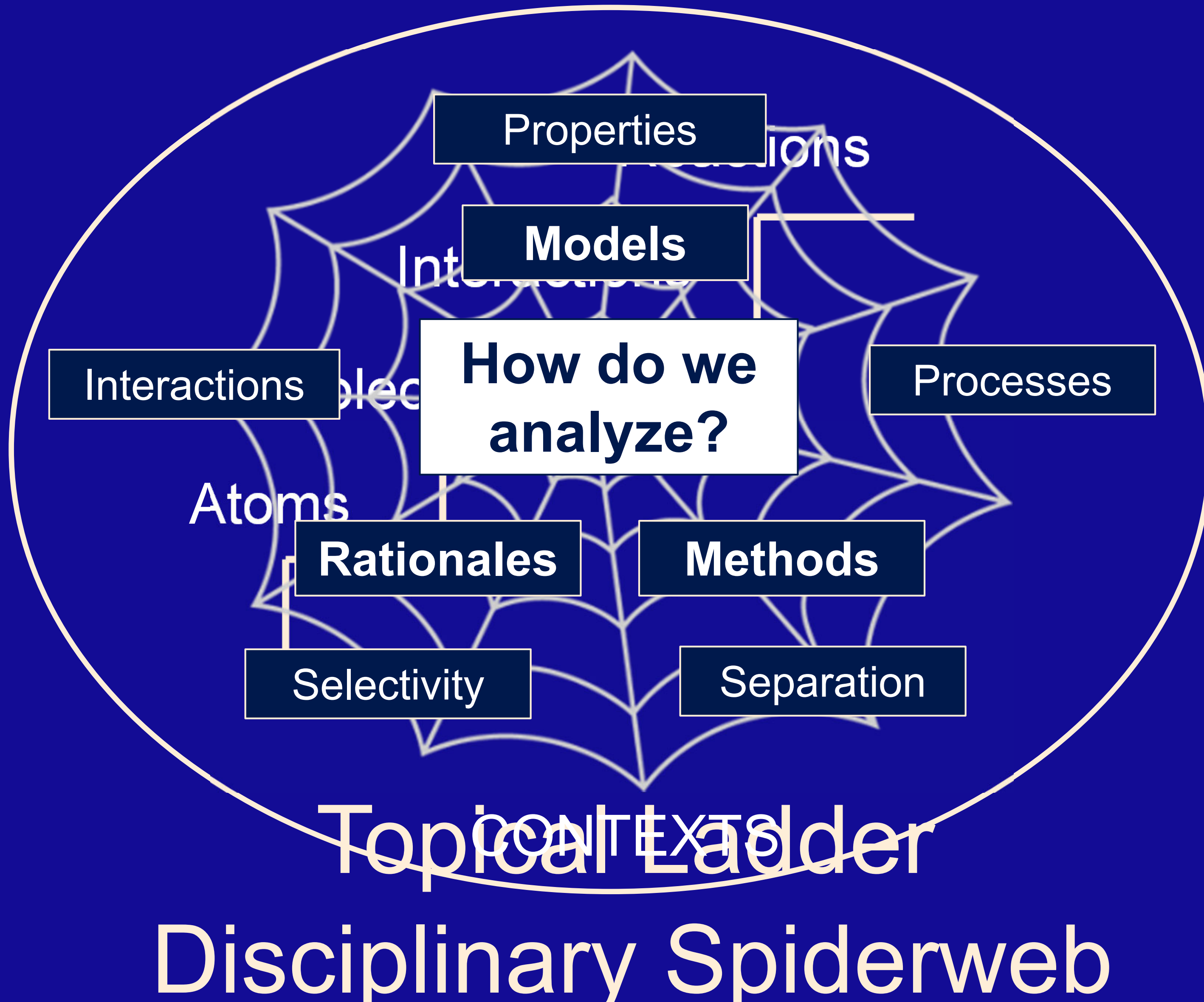
Way of Acting



Talanquer. *Sci. & Educ*. 22, 1757 (2013)

Freire, Talanquer, & Amaral. *Int. J. Sci. Educ*. 41, 674 (2019)

From topics to questions



Essential questions

What is this made of?

What are its impacts?

What properties does it have?

How can we control it?

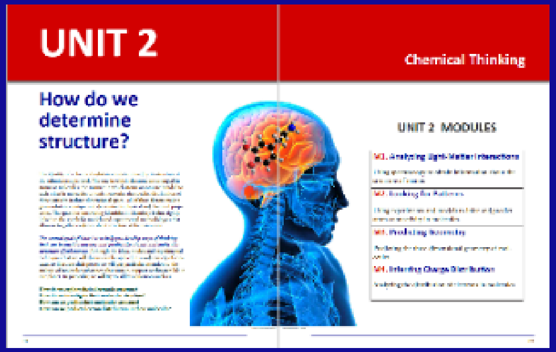
Why does it happen?

How does it happen?

Talanquer & Pollard. *Chem. Educ. Res. Pract*. 11, 74 (2010)

Instructional tasks

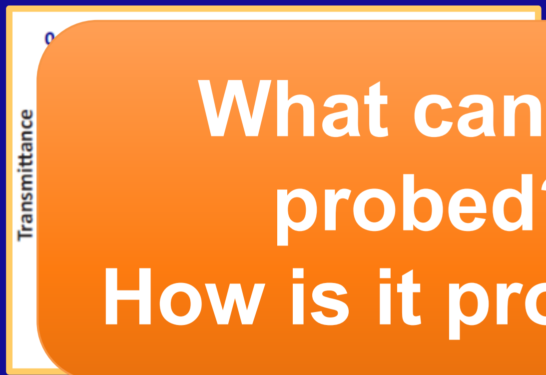
What is in your breath?

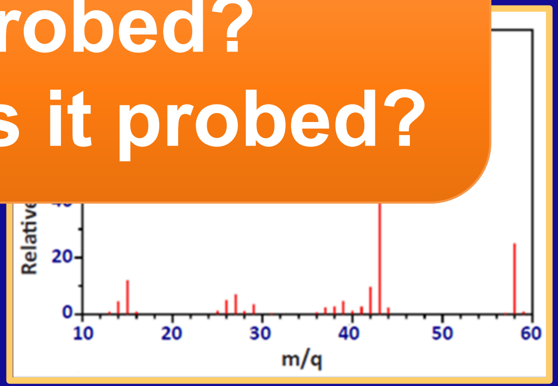


DATA ANALYSIS

MODELING

62.0% C
10.5% H





What can be probed?
How is it probed?

What can be inferred and how?
How is it justified?

SENSE MAKING

Change to instruction

Changes in teaching strategies and physical setting to facilitate active cognitive engagement

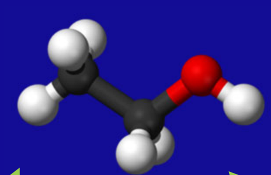
Assessing both process & product

Making student thinking visible and accessible to **formative assessment**

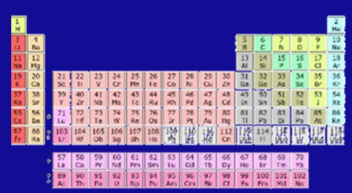
Scaffolding

Explicit Guidance

Inferring and Constructing Evidence

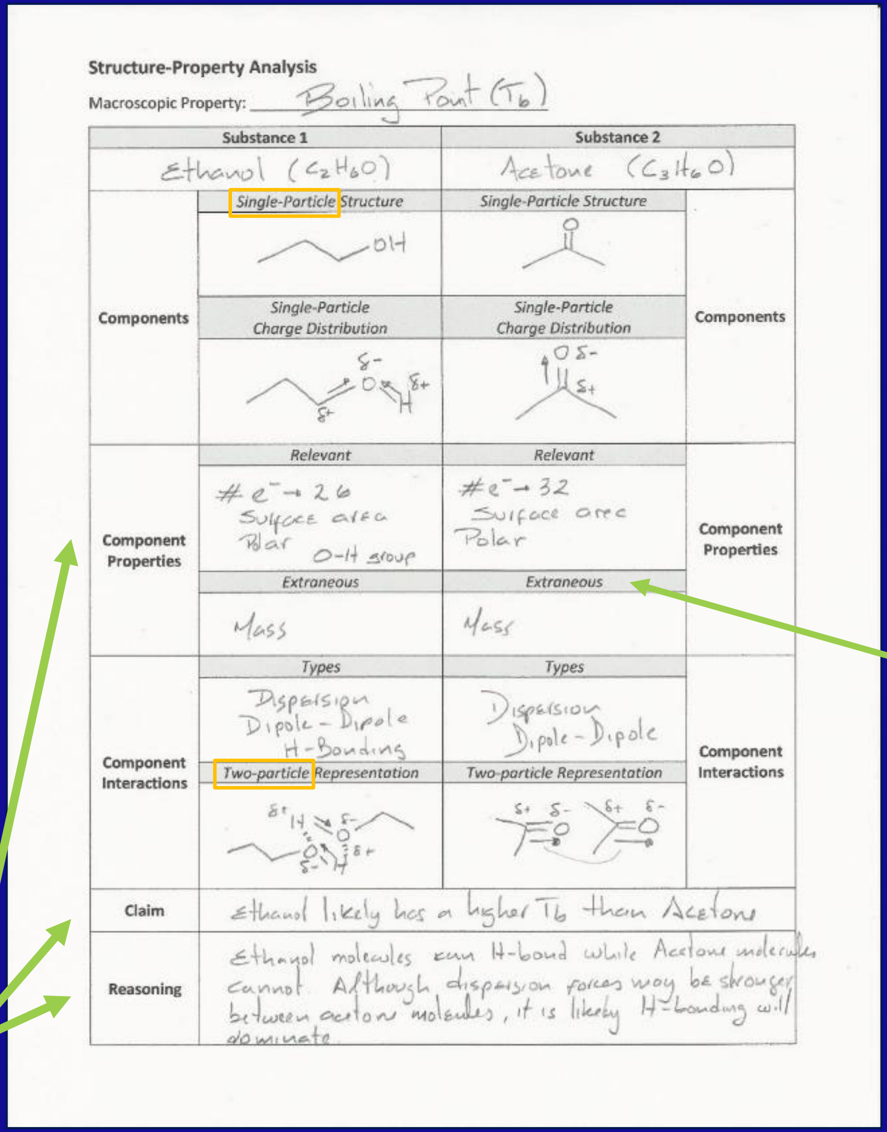


C_2H_6O



Modeling

Argumentation



Structure-Property Analysis

Macroscopic Property: Boiling Point (T_b)

	Substance 1	Substance 2	
	Ethanol (C_2H_6O)	Acetone (C_3H_6O)	
Components	Single-Particle Structure	Single-Particle Structure	Components
	Single-Particle Charge Distribution	Single-Particle Charge Distribution	
Component Properties	Relevant: #e⁻ → 26, Surface area, Polar, O-H group	Relevant: #e⁻ → 32, Surface area, Polar	Component Properties
	Extraneous: Mass	Extraneous: Mass	
Component Interactions	Types: Dispersion, Dipole - Dipole, H-Bonding	Types: Dispersion, Dipole - Dipole	Component Interactions
	Two-particle Representation	Two-particle Representation	
Claim	Ethanol likely has a higher T_b than Acetone		
Reasoning	Ethanol molecules can H-bond while Acetone molecules cannot. Although dispersion forces may be stronger between acetone molecules, it is likely H-bonding will dominate		

Reflection

How is it working?

Assessing intuitive reasoning

We have developed instruments to assess intuitive chemistry reasoning and explore the impact of different interventions

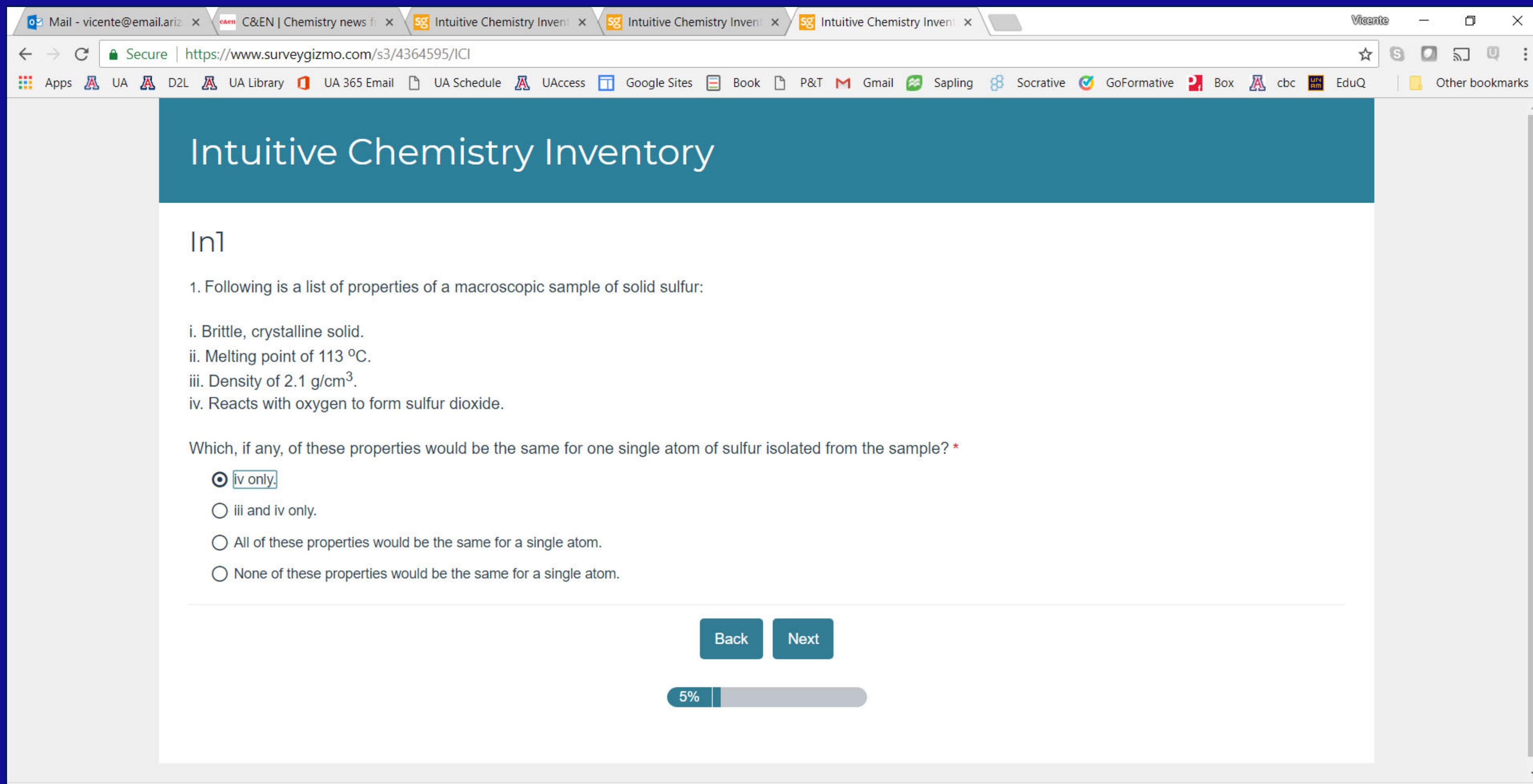
20 multiple-choice questions

INTUITIVE CHEMISTRY INVENTORY (ICI)

- Additivity
- Inheritance
- Matter Tracking
- Energy Investment
- Centralized Causality

https://www.surveygizmo.com/s3/4364595/ICI

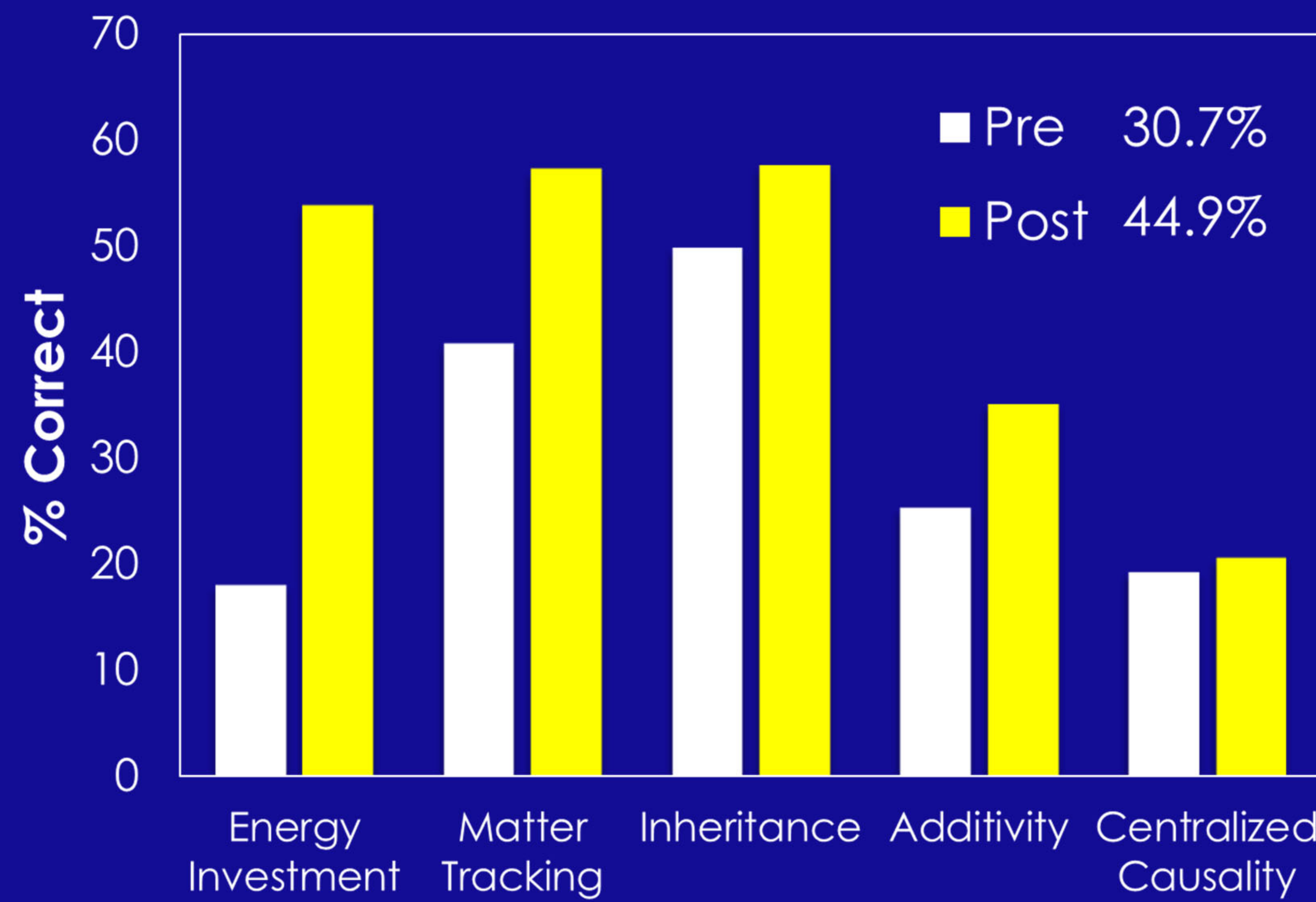
ICI



https://www.surveygizmo.com/s3/4364595/ICI

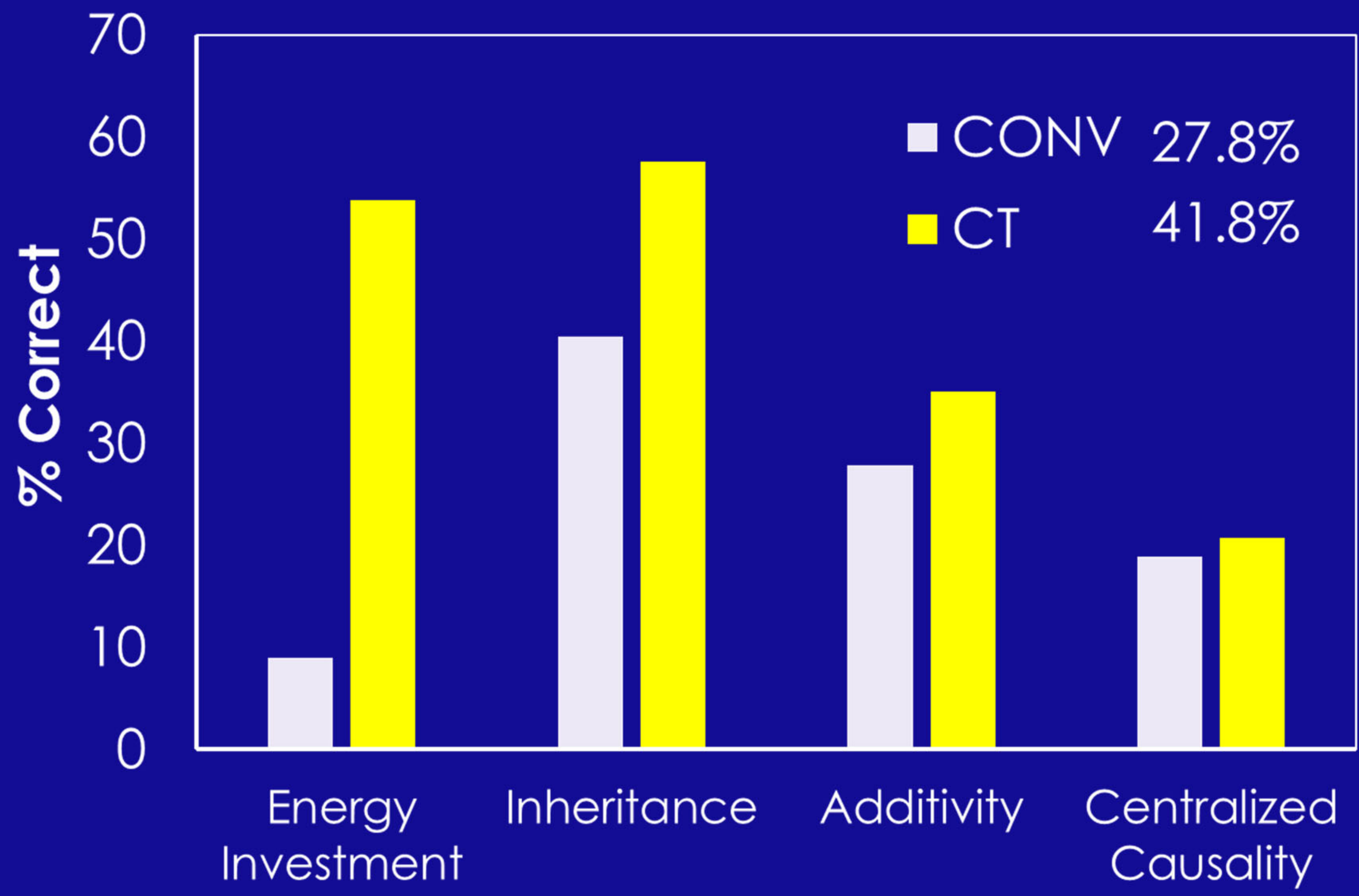
Impact

We use the ICI in a pre-post format in our first-year General Chemistry sequence



ICI

We used the ICI to compare (post) with past performance before intervention



Controlling intuition

- To what extent are the results in the ICI affected by uncontrolled intuitive reasoning?
- Would students' performance improve if they are somewhat prompted to control their intuition?

21. Heat is given off when hydrogen burns in air according to the equation $2H_2 + O_2 \text{-->} 2\,H_2O$. Which of the following is responsible for the heat? *

- [ ] Heat is released when hydrogen and oxygen bonds are broken
- [ ] Heat is produced when hydrogen-oxygen bonds are formed
- [ ] Heat is released when bonds in the reactants are broken and when bonds in the products are formed
- [ ] Heat is released because hydrogen is hotter than water

N = 1076

Metacognitive control

21. Heat is given off when hydrogen burns in air according to the equation $2H_2 + O_2$ --> $2\ H_2O$. Which of the following is responsible for the heat? *

- [ ] Heat is released when hydrogen and oxygen bonds are broken
- [ ] Heat is produced when hydrogen-oxygen bonds are formed
- [ ] Heat is released when bonds in the reactants are broken and when bonds in the products are formed
- [ ] Heat is released because hydrogen is hotter than water

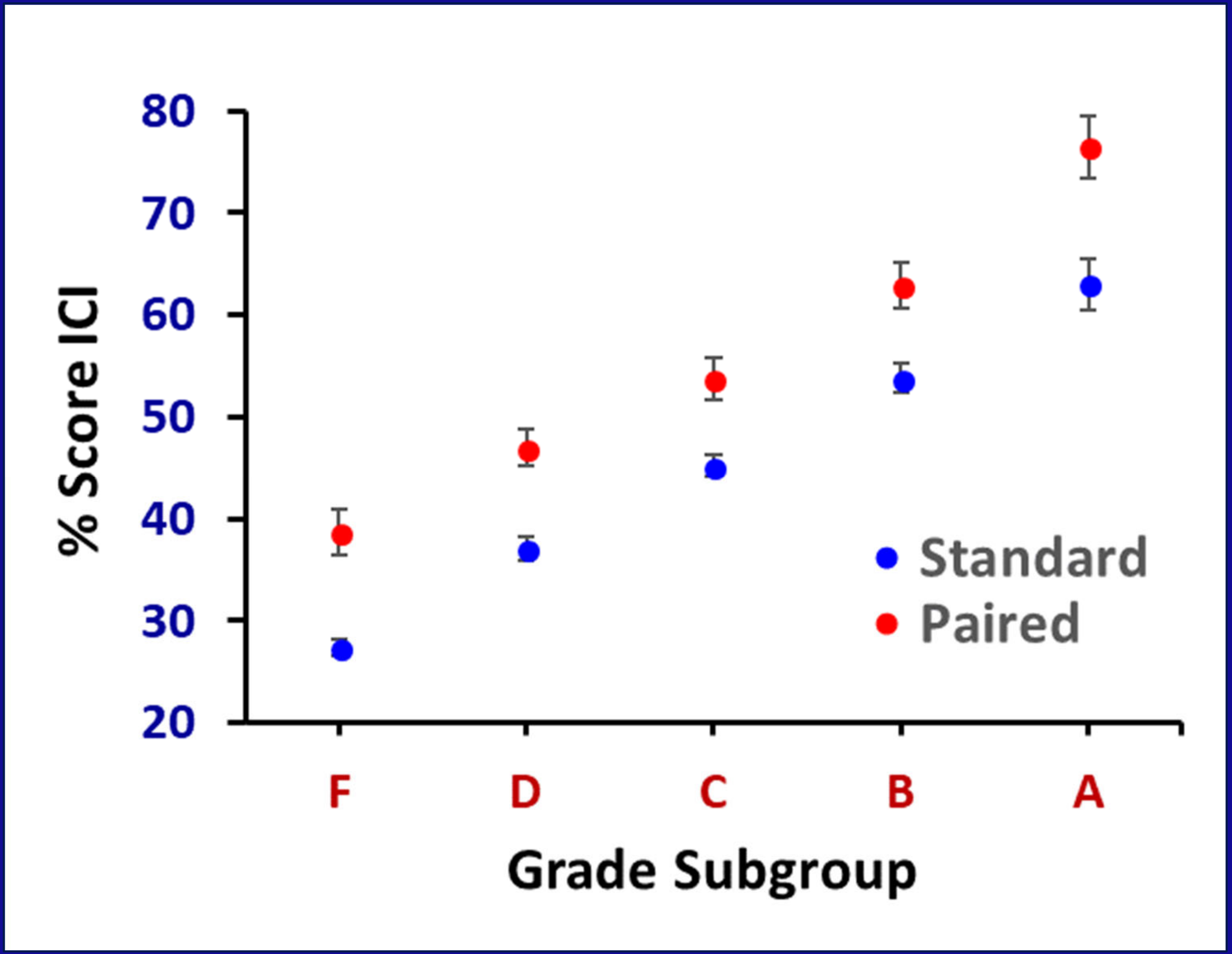
22. Select the option below that you think is most commonly chosen by students who get this question wrong because they do not carefully reflect on what the question is asking or are misguided by their intuition: *

- [ ] Heat is released when hydrogen and oxygen bonds are broken
- [ ] Heat is produced when hydrogen-oxygen bonds are formed
- [ ] Heat is released when bonds in the reactants are broken and when bonds in the products are formed
- [ ] Heat is released because hydrogen is hotter than water

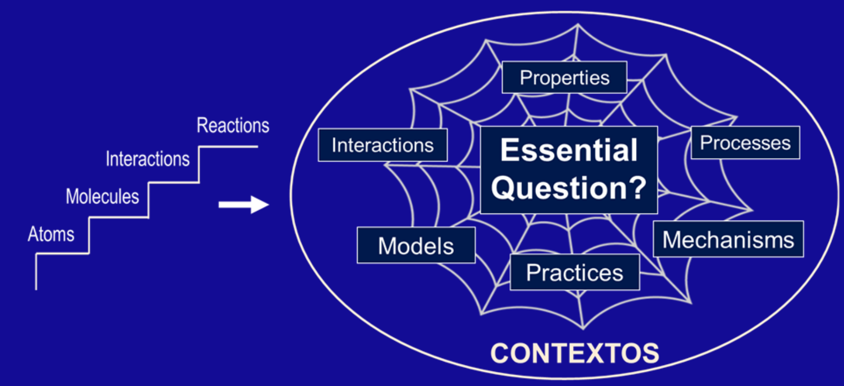
N = 397

Overall comparison

Students divided in groups based on their performance on final ACS standardized exam



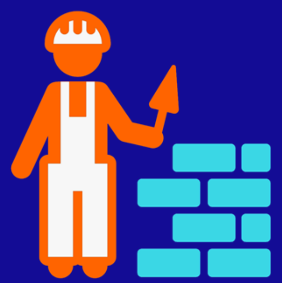
Concluding remarks



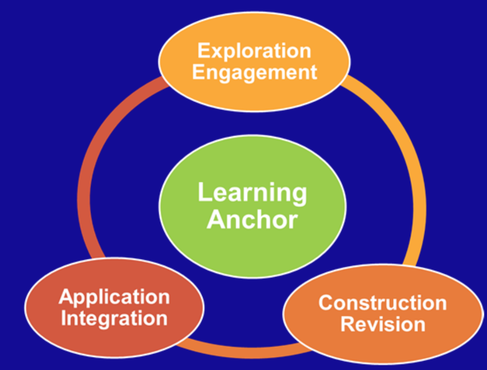
R E S E A R C H

Building Inferences

Making Decisions



Constructing Rationales

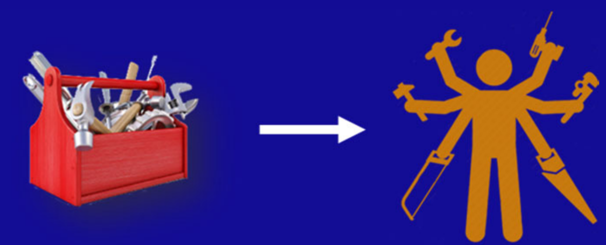


Curriculum

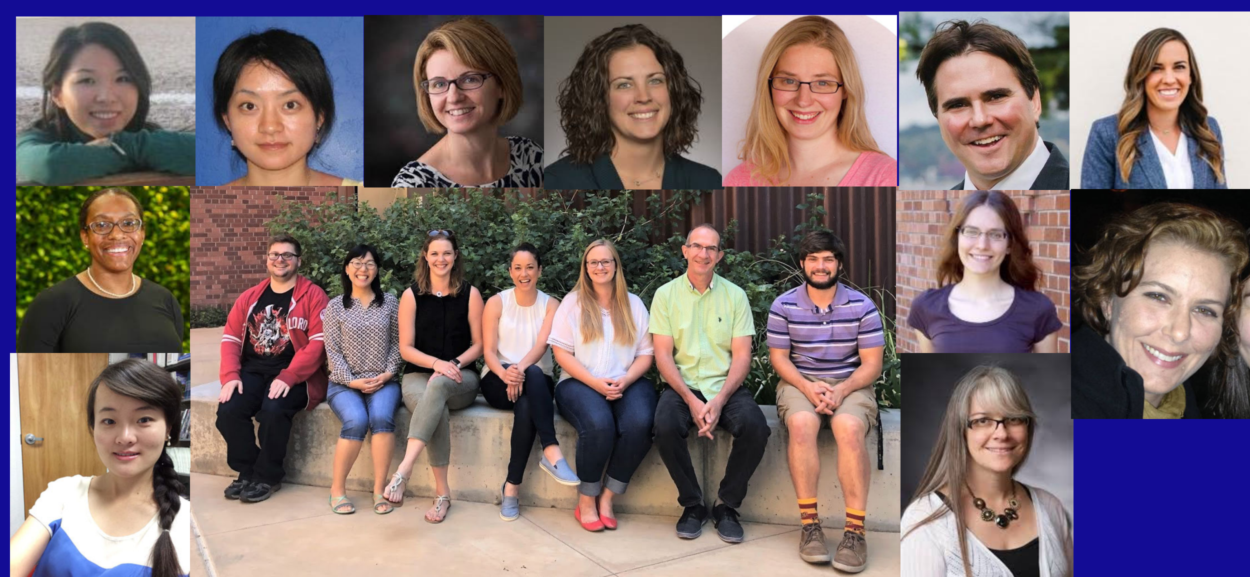
Instruction

Assessment

P R A C T I C E



Acknowledgments



Thank You!

Contact

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https://sites.google.com/site/talanquerchemed/

https://sites.google.com/site/chemicalthinking/

Questions? Comments?