

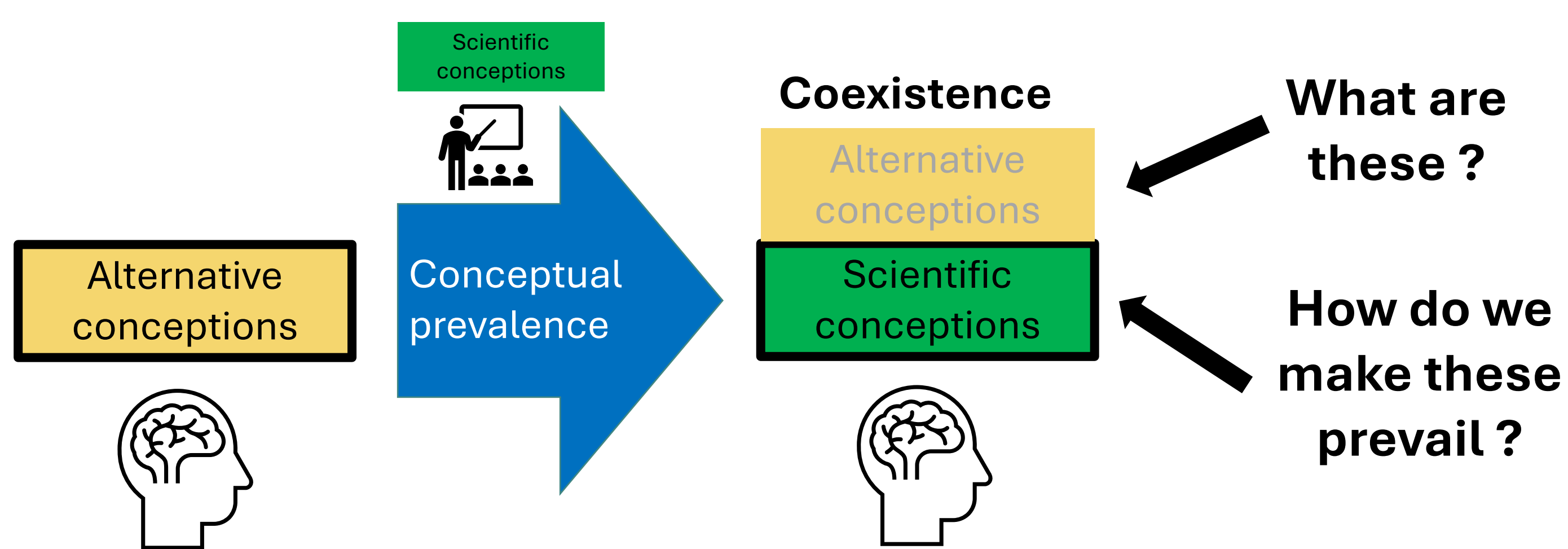
What are students' alternative conceptions of entropy and the second law of thermodynamics?

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Abstract

Entropy and the second law of thermodynamics have long been identified as major difficulties in the physical chemistry curriculum at undergraduate level, and several alternative conceptions (AC) have been identified, many of them attributable to the misfit disorder metaphor. In this study, we observe and critically discuss these ACs and reveal new ones thanks to a supplemented and modified multiple-choice questionnaire with written justification based on the literature. The test was undertaken by N = 581 scientific and engineering undergraduates following a classical macroscopic thermodynamics course and completed by N = 20 interviews of chemistry undergraduates. Our results support multiple ACs identified in the literature and report 7 new ones, backed by their presence in erroneous answers in multiple chemical contexts in the written answers and the interviews. The pre/post design data around the classical macroscopic course revealed little to no conceptual change. This novel evidence also lays ground for a teaching proposal involving a systematic microscopic comparison of the relative magnitudes of internal degrees of freedom contributions on entropy to tackle these ACs.

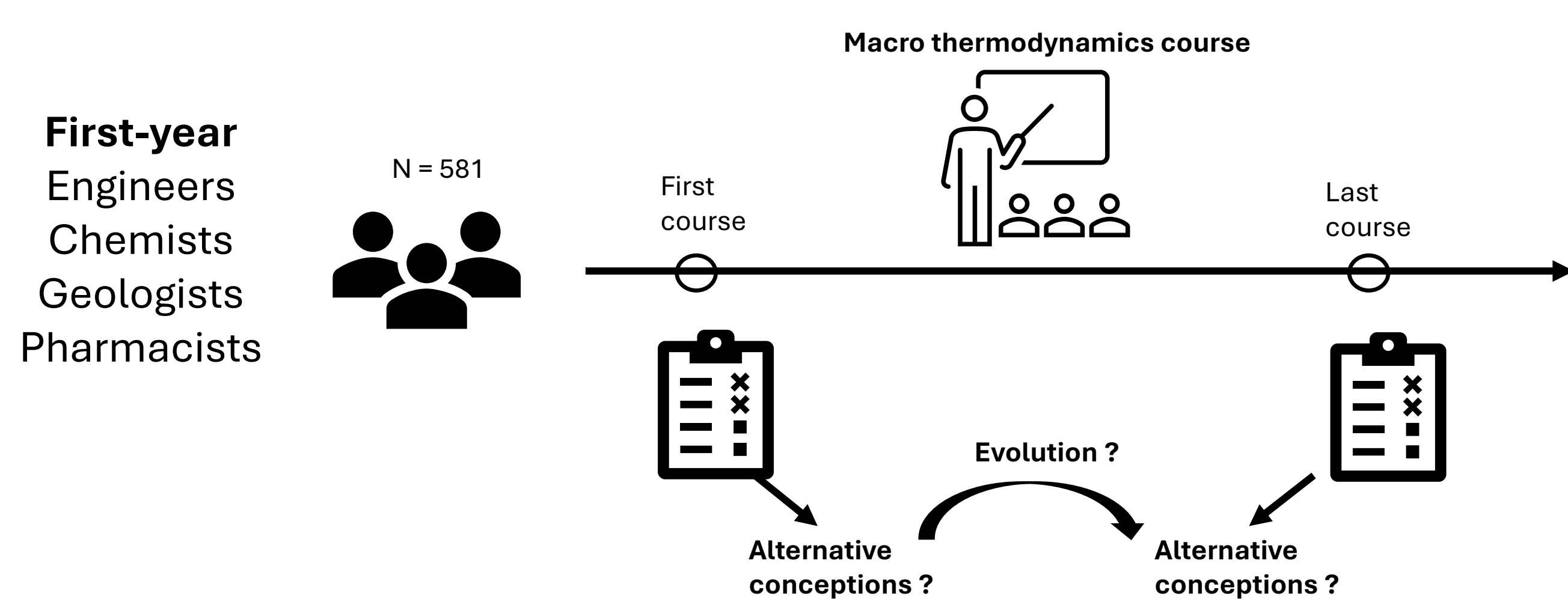
Context



Objective

Observe, define and track students' alternative conceptions about **entropy** and the **second law of thermodynamics** in a first-year thermodynamics course at university

Method - Timeline



Method - Questionnaire



Conceptual questions with/out justification

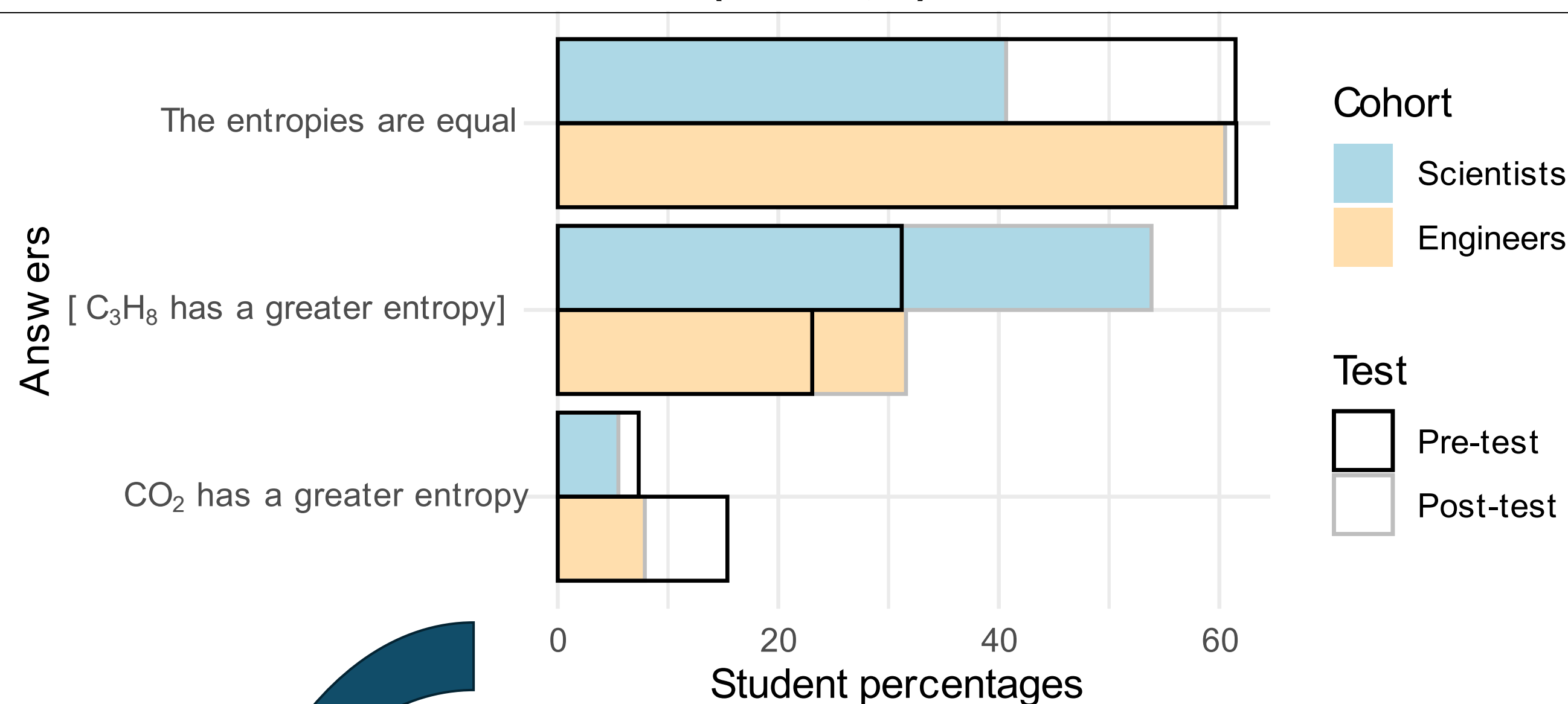
Example : how do the entropies of one mole of $\text{CO}_2(\text{g})$ and one mole of $\text{C}_3\text{H}_8(\text{g})$ compare ? (same T, V)

- $S(\text{CO}_2) > S(\text{C}_3\text{H}_8)$
- $S(\text{CO}_2) = S(\text{C}_3\text{H}_8)$
- $S(\text{CO}_2) < S(\text{C}_3\text{H}_8)$

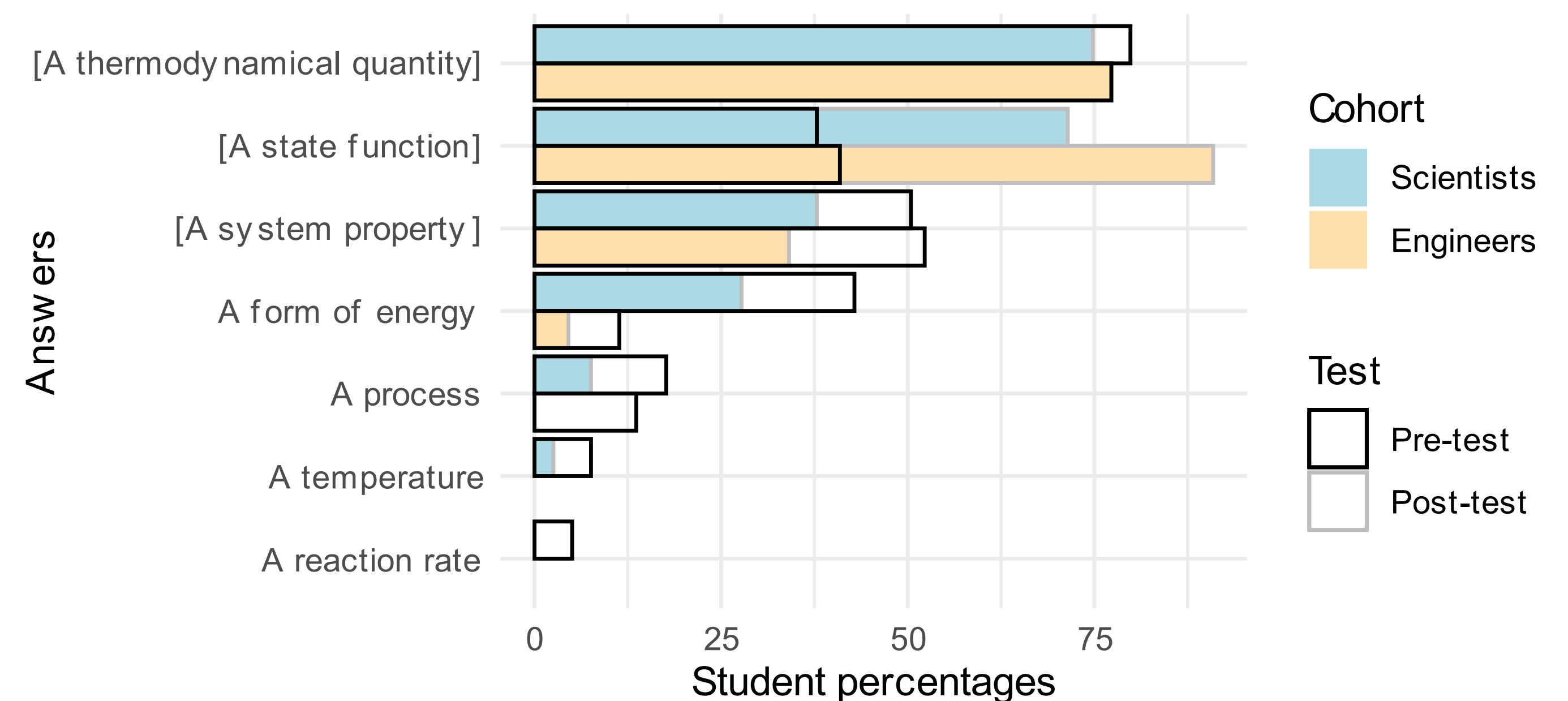


Results

How do the entropies of one mole of $\text{CO}_2(\text{g})$ and one mole of $\text{C}_3\text{H}_8(\text{g})$ compare ? (same T, V)

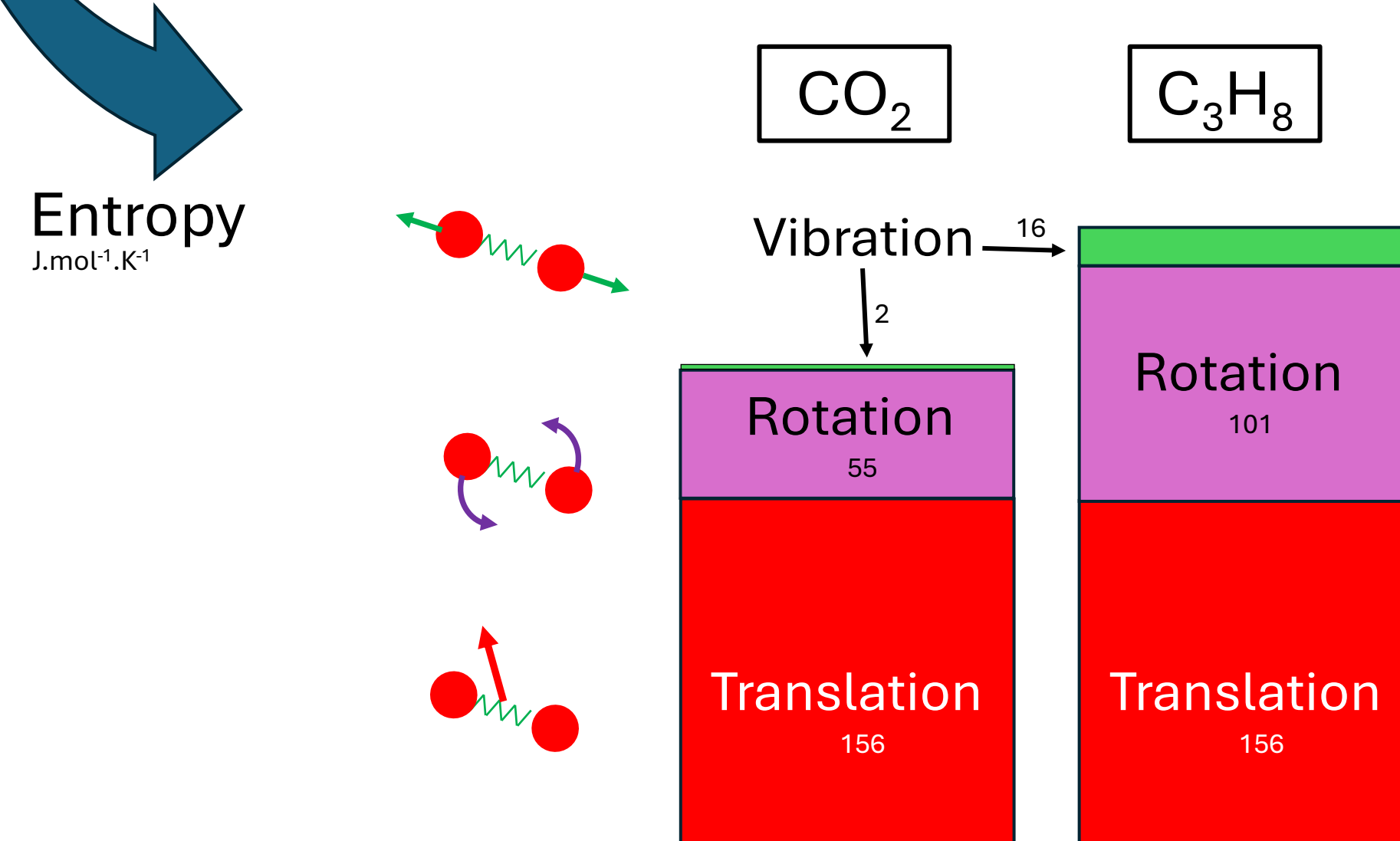


According to you, entropy is....



Mixing	Entropy always increases when two substances are mixed up.
Substance	Entropy is independent of the internal structure of the pure substance contained in a system.
Levels	Entropy is linked to the number of particles, whatever the level (subatomic, atomic, molecular, or macroscopic).
Collisions	If molecules have a higher chance of colliding, their entropy is higher.
Freedom	Entropy is proportional to the freedom of movement of particles.
Stability	Molecules that are chemically more stable have a lower entropy.
Ordering	Crystallisation requires an energy input to organize liquid molecules into an ordered solid.

Perspectives



Take home message

1. Students possess numerous alternative conceptions about entropy and the second law that are (very) resistant to change
2. Macroscopic thermodynamics does not seem to provoke conceptual change, especially for disorder-related conceptions
3. The integration of micro elements in a macroscopic teaching might help improve conceptualization