General chemistry students' conceptual understanding of thermochemistry in a biological context

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Background

- While students can readily perform thermochemistry calculations, they struggle with true conceptual understanding.[1]
- It is important for chemistry students to be able to incorporate other disciplines, especially since many students in general chemistry come from other majors (i.e. biology or health sciences).[2]

Methodology

- Data was collected from a group activity in a second semester General Chemistry course at a large Midwestern institution (N=161). Students had already been taught about these thermochemistry concepts.
- Students worked in groups (N=37) of 2-4 on a worksheet of conceptual thermochemistry problems. The worksheet included a brief section about cellular respiration at the top, framing a biological context.
- Students recorded written responses but were also asked to record their group conversations using a cellphone. Only some groups (N=18) had files that could be interpreted.

Coding

- Three categories were used: correctness, justification, and context.
- For correctness, answers were scored as 'correct', 'partially correct' (for certain questions only), or 'incorrect' based on the written responses.
- Justification from audio files was coded as 'correct' or 'incorrect'. Only groups with audio files were included for questions A, B,D, and F. *All groups were coded for questions C and E since they specifically asked for written reasoning.*
- Context was coded as 'students referenced the context' or 'students did not mention the context'. Only groups with audio files were included for questions A, B,D, and F. *All groups were coded for questions C and E since they specifically asked for written reasoning.*

Worksheet

Free energy change of a reaction is important in the study of metabolism, because they can tell us whether reactions can supply energy for cellular work. Cellular respiration is represented by the following equation/reaction:

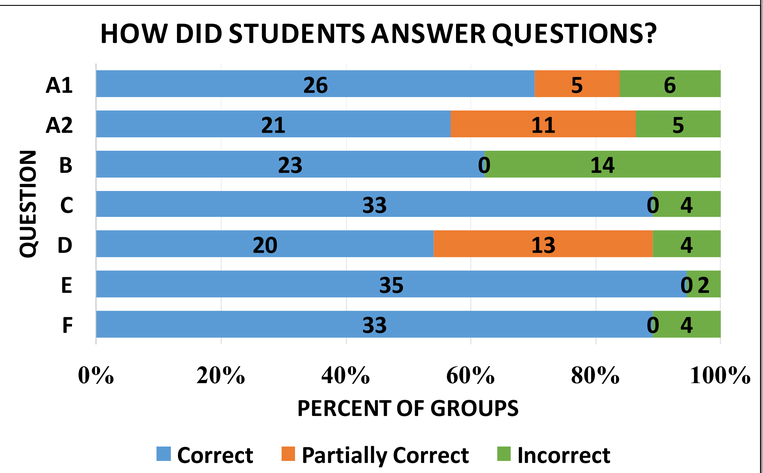
$C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O$, $\Delta G = -2{,}870$ kJ/mol.

Question	Correct Answer
A1. What is the importance of cellular respiration?	Cellular respiration helps humans to convert glucose/nutrients into usable energy and release carbon dioxide. *Answers that were factual statements but did not iterate the importance were coded as 'partially correct'.*
A2. What is the other product of the reaction not included in the equation?	Energy. *ATP was marked as 'partially correct' since it is not the direct product of this reaction, but is a further product of cellular respiration.*
B. How does the entropy of your reactants compare to that of your products?	The products have more entropy than the reactants.
C. Do you expect the reaction to be endothermic or exothermic? Why?	Exothermic.
D. Draw an energy level diagram to illustrate your choice in c above.	*Unlabeled graphs with the correct shape were scored as 'partially correct'.*
E. Using $\Delta G = \Delta H - T\Delta S$, prove whether the process is spontaneous or non-spontaneous with reasoning from your understanding of cellular respiration.	Spontaneous.
F. Which species is oxidized in the reaction?	Glucose is oxidized.

Research Questions

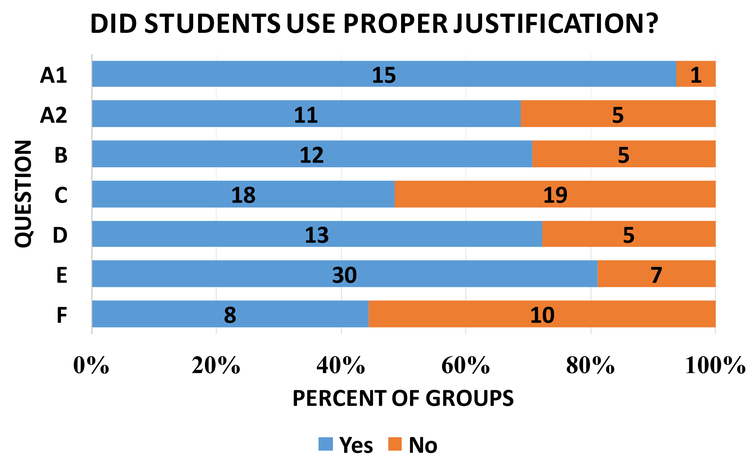
1. To what extent do students understand thermochemistry concepts?
2. Are students able to properly justify their reasoning?
3. In what ways do students use the biological context to shape their responses?

Correctness



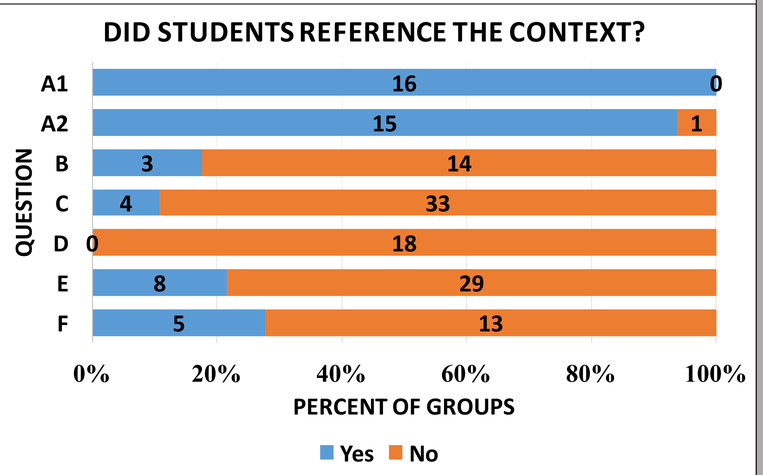
- More than 50% of groups answered correctly for all 7 questions.
- In A2, almost 30% of groups confused ATP with energy, relying on their knowledge from biology.
- Almost 1/3 of energy level diagrams in D were unlabeled, possibly indicating a lack of student understanding about what the shape of the graph represented.

Reasoning



- While many answered questions correctly, a sizable amount of groups were not able to correctly justify their answers.
- Students primarily struggled with reasoning for entropy, enthalpy, and oxidation.
- Recording transcripts revealed that even when some groups justified their responses correctly, they did so with seemingly 'memorized', algorithmic reasoning rather than actual conceptual understanding.

Context



- After A1 and A2, which specifically mentioned the context, students largely did not reference cellular respiration or biology at all.
- Students mainly focused on the chemistry concepts and treated the activity as a chemistry exercise rather than an interdisciplinary one.

Conclusion

- Although students are able to determine the correct answers to conceptual thermochemistry problems, they are not readily able to explain their reasoning.
- Unless specifically prompted to do so by the question, students did not use or even mention the biological context.

Implications

- Thermochemistry activities should include conceptual elements and justification sections to prompt students to work through their reasoning. Emphasis should be placed on enthalpy, entropy, and spontaneity.
- Instructors should design interdisciplinary activities with the different disciplines incorporated throughout, rather than solely use questions from one discipline and change the wording to match the other discipline.

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References

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