Conceptual understanding and context: Free energy

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Introduction:

- Context: Question with a biology background assigned in a chemistry classroom.
- Students need prompting to apply context; applications are not seen without guidance[1,2].
- Students spit back vocabulary and statements verbatim from classes, lectures, notes, and textbooks with no application to context[1].
- Students believe they are making deep connections, but connections are actually shallow and superficial[2].
- Science classes teach topics that are alike, but are taught in many different ways. This includes different graphs, terms, and definitions.
- Students are expected to make connections between disciplines, yet very few classes make an effort to make connections clear for the students.
- Hypothesis: Students will use context less as they work through worksheet and only when prompted by the question, but will be successful in using the context to guide their answer.

Research Questions:

1. When presented with a different discipline context-based question, to what extent do students use both disciplines as they answer the question?
2. To what extent do they use both disciplines *successfully*?

Methods:

- Data was collected in a general chemistry (II) spring semester class.
- 137 students in groups of 3-4 students (37 groups) to complete a free energy worksheet.
- Students had just covered the chapter "entropy, free energy, and equilibrium".
- Students were not taught any information on cellular respiration.
- Two sources of data:
  - Audio transcripts
  - Written worksheets

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

a. What is the importance of cellular respiration (a1)? What is the other product of the reaction not included in the equation (a2)?
b. How does the entropy of your reactants compare to that of your products?
c. Do you expect the reaction to be endothermic or exothermic? Why?
d. Draw an energy level diagram to illustrate your choice in c above.
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.
f. Which species is oxidized in the reaction?

Data Analysis:

5 levels of analysis:

- Analyzed as correct or incorrect for each question.
- Assessment of conceptual understanding.
- Analyzed integration of two content areas – biology and chemistry, as well as transition.
- Language fluency (graphs or audio conversations).
- Interactions within groups (taking turns, helping each other, arriving at a consensus).

Results:

Question A

Worksheet Analysis:

# of Worksheets	Biology	Chemistry	Transition	Total
Correct	2	11	16	29
Incorrect	8	6	1	15
Total	10	17	17	44

Figure 1. The number of correct and incorrect statements made for question A1.

Sample answers for a1 included:

Biology- "Creates H_2O for the body's use"
Chemistry- "Creates needed energy"
Transition- "Provides energy for living organisms to perform necessary functions."

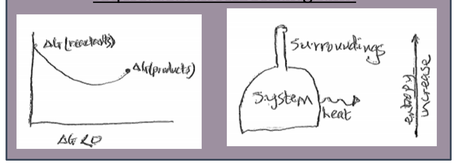
Transcript Samples:

-"What is this- a **carbohydrate**?
-That's **glucose.**
-Glucose?
-Yeah.
-Cellular respiration- **glucose goes into the leaves then it goes into digestion.** And then NADPH is basically taking in blank blank to give off blank blank.
-So this is energy going into the system.
-Yup.
-So that the cell is using sugar and oxygen to make energy or to get energy. Like to do work."

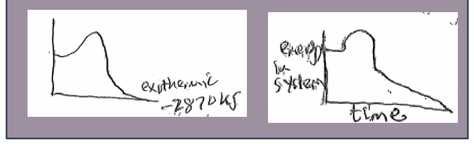
Question D

Of the 37 worksheets, 33 were the correct shape but many lacked other important aspects of graphs (labels, titles, formal shape). The figures below are samples of student drawings.

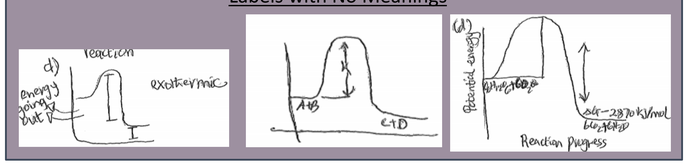
Copied but incorrect diagrams



Zero Potential Energy



Labels with No Meanings



Question E

Worksheet Analysis:

# of Worksheets	Biology	Chemistry	Transition	Total
Correct	1	28	6	35
Incorrect	0	2	0	2
Total	1	31	6	37

Figure 2. The number of correct and incorrect statements made for question E.

Incorrect Explanations	Temperature Confused	ΔG is negative	Non-spontaneous	Other
Total	12	23	2	4

Figure 3. Incorrect proof main topics for question E.

While students were able to get the correct answer, a proof using the given equation was almost never provided. Most explanations fell under 3 categories that were not proofs. Conversations showed that students used the context in their analysis, but the context was more often used incorrectly and added to the confusion.

Transcript Samples:

-"Should we say **298 because that is what we have been getting?**
-I don't know if it is a coincidence or I don't know
-But we can't assume and we don't know for sure and we don't know what delta S is either.
-But I wonder if we can find out
-Because it will be the same delta H and T
-But I wonder if we can find out if it is a **negative or positive**
-Well exothermic processes tend to be spontaneous
-I don't know how we can use that equation because we don't have actual numbers because any of that can be positive or negative."

-"Well your **temperature would be your body temp**, wouldn't it?
-Um…. Yes….?
-So Fahrenheit to Kelvin…. That would be our temp. Our change in H is going to be….."

Discussion and Conclusions:

- Students struggled with basic concepts, such as entropy, and whether the reaction was endo- or exothermic.
- Often, language such as graphs and vocabulary, was used incorrectly or inappropriately.
- Students did not know how to use information from a textbook or the internet.
- Most students did not consider the context in their responses (such as the fact that cellular respiration happens in a living body).
- Even though most students were successful in answering questions in the worksheet, integrating biology and chemistry in the context was problematic.
- It was apparent in some cases that the context confused students as they reasoned through answers.

Implications:

- If students do not have strong grasp of a concept in one discipline, they will struggle with applying it in a different context.
- It is important for instructors to model integration of ideas across disciplines.
- Students need opportunities to practice fluency in discipline specific academic language.

Future Research:

1. Do students actively shift between two disciplines when thinking about a concept that might be approached differently?
2. How would students solve a context problem that does not fit neatly into specific disciplines?
3. To what extent do instructors in given disciplines integrate other disciplines into their teaching?

References:
1. Broman, K., & Parchmann, I. (2014). Students' application of chemical concepts when solving chemistry problems in different contexts. *Chem. Educ. Res. Pract.*, 516-529.
2. Bellocchi, A., King, D. T., & Ritchie, S. M. (2016). Context-based assessment: creating opportunities for resonance between classroom fields and societal fields. *International Journal of Science Education*, 1-40.

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