Supporting Information

Adapting Assessment Tasks to Support Three-Dimensional Learning

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ASSOCIATED CONTENT

Here we provide additional examples of assessment items modified to better align with 3D learning.

EXAMPLE S1: USING MATHEMATICS AND COMPUTATIONAL THINKING

The original zero-dimensional question presented in Figure 3 of the paper "Calculate the percent ionization of a 0.030 M solution of fluoroacetic acid (CH_2FCOOH), which has a pH of 2.12." can also be transformed to a cluster of selected-response (SR) items that address the scientific practice of *Using Mathematics and Computational Thinking* as shown in Figure S1. It is important to note that this revised question still does not align with a core idea or crosscutting concept.

Revised Question – Selected Response:

1. What is the percent ionization of a 0.030 M solution of fluoroacetic acid (CH_2FCOOH) if its pH is 2.12. Fluoroacetic acid has a pK_a of 2.59.

   A. 2.5% B. 4.0% C. 25%* D. 40%

2. Which of the following particulate (molecular level) representation best matches your response from question 1?

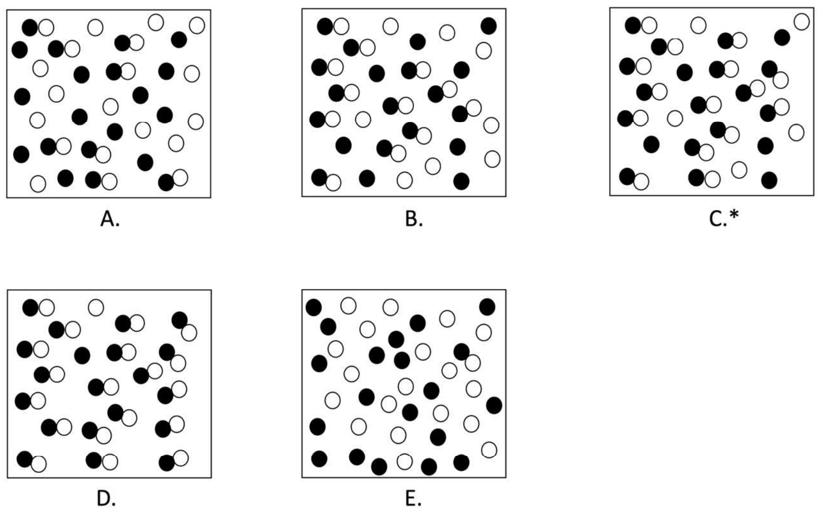


Figure S1. Transformation of a percent ionization calculation item to a selected-response 3D question cluster that addresses the scientific practice of *Using Mathematics and Computational Thinking*. This cluster of items does not contain a core idea or crosscutting concept.

Table S1. Revised SR cluster questions for percent ionization calculation item

Question	*Core Idea*	*Science Practice*	*Crosscutting Concept*
Revised	None	Using Mathematics and Computational Thinking	None

EXAMPLE S2: ANALYZING AND INTERPRETING DATA

As students learn about atomic structure in general chemistry, a common learning goal is "knowing" the periodic trends in the properties of atoms, such as ionization energies, across rows and down columns as illustrated by the original question shown in Figure S2. This question is zero-dimensional and elicits no evidence that students understand the factors that lead to these trends in ionization energies. The revised constructed-response (CR) question in Figure S2 introduces the scientific practice of *Analyzing and Interpreting Data*, the core ideas of *Electrostatic and Bonding*

Interactions as well as *energy: quantum mechanical energy levels and changes*, and crosscutting concept *patterns*.

Original Question:

Which of the following has the largest ionization energy?

A. oxygen* B. lithium C. sulfur D. carbon

Limitations of the Question

1) It does not relate directly to the core idea of Electrostatic and Bonding Interactions.
2) It does not address a Scientific Practice.
3) It asks the students to recall a trend that can be memorized, with no understanding as to why.

Revised Question – Constructed Response:

1. The first seven ionization energies of a third-row element are shown in the graph to the right. Identify the element which this set of data would most likely represent.
2. What information from the graph did you use to identify the element?
3. Use your response to question #2 and your understanding of forces and energy changes to explain how you identified the element based on the data provided in question #1. Your response should describe what the ionization energy is.

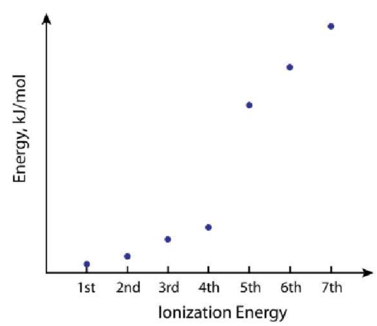


Figure S2. Adaptation of an ionization energy assessment item to a constructed-response task that addresses the core ideas of *Electrostatic and Bonding Interactions* and *Energy: Quantum Mechanical Energy Levels and Changes*, scientific practice of *Analyzing and Interpreting Data*, and crosscutting concept of *Patterns*.

Table S2. Transformation of a SR question into a CR cluster of questions for ionization energy

Question	*Core Idea*	*Science Practice*	*Crosscutting Concept*
Original	None	None	None
Revised	Electrostatic Interactions and Bonding; Energy: Quantum Mechanical Energy Levels and Changes	Analyzing and interpreting data	Patterns

EXAMPLE S3: CONSTRUCTING EXPLANATIONS AND ENGAGING IN ARGUMENT FROM EVIDENCE

Figure S3 shows how a boiling-point ranking task can be transformed to constructed-response and selected-response tasks that have the potential to engage students in the practice of *constructing explanations and engaging in argument from evidence.*

Original Question:

Which of these substances has the highest boiling point?

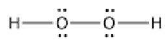
A. H_2 B. CH_3OCH_3 C. HOOH D. CO_2

Limitations of the Question

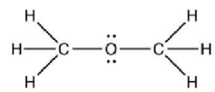
1) It does not address a Scientific Practice.
2) It allows students to use a heuristic to predict the answer without understanding why.

Revised Question – Constructed Response:

Use the structures provided below to answer the following questions:



hydrogen peroxide



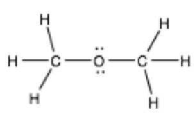
dimethyl ether

1. In liquid hydrogen peroxide, what intermolecular forces would be present?
2. In liquid dimethyl ether, what intermolecular forces would be present?
3. Draw three molecules of hydrogen peroxide and then dimethyl ether showing the **strongest** intermolecular force for each compound labeling the location and type of IMF you are drawing.
4. Using the relative strengths of intermolecular forces and your understanding of energy changes, which compound would have the higher boiling point? Explain your reasoning.

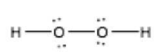
Revised Question – Selected Response:

One of these two compounds is a **liquid** at room temperature. **Choose the compound**, the **evidence** you are using to make the claim, and the **reasoning** that allows you to make this claim.

Compound:



I



II

Evidence:

III. Compound I is heavier than compound II.
IV. Compound I has more hydrogens and can form more hydrogen bonds than II.
V. Compound II has both hydrogens and oxygens capable of hydrogen bonding.

Reasoning:

VI. Heavier molecules are more likely to cluster together and form liquids because they are attracted to each other strongly by London dispersion forces.
VII. Molecules capable of hydrogen bonding are strongly attracted to each other and tend to cluster together to form liquids.

A. I, III, VI B. I, IV, VII C. II, V, VII* D. Not enough information

Figure S3. Adaptation of a boiling point ranking task to address the core idea *Atomic/Molecular Structure and Properties*, scientific practice *Constructing Explanations and Engaging in Argument from Evidence*, and crosscutting concepts *Structure and Function* and *Cause and Effect: Mechanism and Explanation*. [Previously published in *Laverty, J. T.; Underwood, S. M.; Matz, R. L.; Posey, L. A.; Carmel, J. H.; Caballero, M. D.; Fata-Hartley, C. L.; Ebert-May, D.; Jardeleza, S. E.; Cooper, M. M. Characterizing College Science Assessments: The Three-Dimensional Learning Assessment Protocol. PLoS ONE 2016, 11, e0162333.]*

Table S3. Transformation of a SR question into CR and SR questions for boiling ranking task

Question	*Core Idea*	*Science Practice*	*Crosscutting Concept*
Original	Atomic/Molecular Structure and Properties	None	Structure and Function
Revised CR	Atomic/Molecular Structure and Properties; Electrostatic and Bonding Interactions; Energy: Atomic/Molecular	Constructing Explanations and Engaging in Argument from Evidence	Structure and Function; Cause and Effect
Revised SR	Atomic/Molecular Structure and Properties	Constructing Explanations and Engaging in Argument from Evidence	Structure and Function; Cause and Effect: Mechanism and Explanation

REFERENCES

1. *Laverty, J. T.; Underwood, S. M.; Matz, R. L.; Posey, L. A.; Carmel, J. H.; Caballero, M. D.; Fata-Hartley, C. L.; Ebert-May, D.; Jardeleza, S. E.; Cooper, M. M. Characterizing College Science Assessments: The Three-Dimensional Learning Assessment Protocol. PLoS ONE 2016, 11, e0162333.*