15. Two aqueous solutions of ionic compounds reacted to form a solid. This reaction was accompanied by a decrease in entropy of the system and an increase in the entropy of the surroundings. Which best explains the increase in the entropy of the surroundings?

A. Water autoionized: $H_2O(\ell) \rightleftharpoons H^+(aq) + OH^-(aq)$

B. Entropy was transferred from the system to the surroundings.

C. Energy was transferred from the system to the surroundings.

D. Mixing solutions always causes entropy to increase.

How confident are you about your response? Place an 'X' anywhere on the line.

0% 20% 40% 60% 80% 100%

Not confident (just guessing) **Confident** (absolutely certain)

Figure 2. Question from the E_2DPI focusing on entropy changes, with the confidence scale.

example, Figure 2 depicts Question 15, which focuses on student understanding of how an entropy change occurs during a precipitation reaction. Each of the distractors (options A, B, and D) were developed from responses given by students in the interviews:

Henry, BPC:

I would probably say... [laughs] umm... one likely candidate would be water which could go from liquid to ions. Umm that could possibly be one thing.

Jana, PC:

[The surroundings are] becoming more random and disordered. Umm... it's equal and opposite of the system [laughs]... whatever [entropy] was lost from the system went to the surroundings.

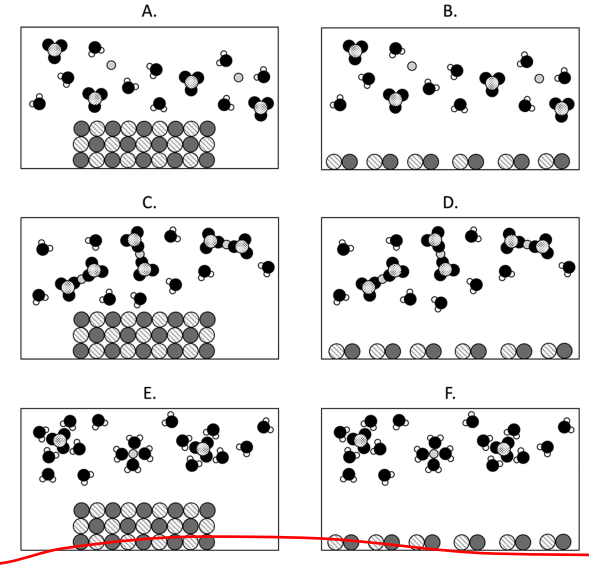
Ryan, GC:

But umm in the solution umm dumping in more particles umm that increases in the entropy because then there's more things bouncing around in umm a space, in a small space.

Students were asked to indicate their confidence in each answer by placing an "X" on a scale that followed each item (Figure 2). The scale ranged from 0% (just guessing) to 100% (absolutely certain, Figures 2 and 3). The confidence scale provides the instructor with information about the strength of the ideas held by the students. This scale was used over a Likert type scale in order to provide continuous data to be analyzed.[39−41] Previous literature has referred to the confidence scale as a second tier to each item.[42,43] However, the word "tier" in this manuscript refers to a pair of two items (including their confidence scales), not to one item and its confidence scale.

14. Which image best represents the products of the reaction below?

$MgCl_2(aq) + 2\,AgNO_3(aq) \rightarrow 2\,AgCl(s) + Mg(NO_3)_2(aq)$



How confident are you about your response? Place an 'X' anywhere on the line.

0% 20% 40% 60% 80% 100%

Not confident (just guessing) **Confident** (absolutely certain)

Figure 3. E_2DPI item assessing student knowledge of the particulate representation of the products of a precipitation reaction.

E_2DPI Administration

The 28-question E_2DPI was administered through three data collection opportunities at a medium-sized midwestern university (Institution 1) and a large, research intensive midwestern university (Institution 2). The inventory was first administered to students at Institution 1 who were enrolled in either physical chemistry (PC, n = 10) or biophysical chemistry (BPC, n = 43) at the beginning of the Spring 2018 semester. At the end of the Spring 2018 semester, the E_2DPI was administered to second-semester general chemistry (GC II, n = 383) students at Institution 1. The E_2DPI was also administered in Fall 2018 to students in a postorganic General Chemistry II course (PO-GC II, n = 160) at Institution 2, where the curriculum consisted of a 1:2:1 course sequence in which one semester of general chemistry was followed by two semesters of organic chemistry and then finally by one semester of General Chemistry II.[44] Students responded to the inventory using paper and pencil by circling their answers and marking an "X" on each confidence scale. In all administrations, students answered the questions on the E_2DPI after they had been taught and tested on dissolution, precipitation, and thermodynamics. The inventory required 15−20 min to complete.

Response Process Interviews

Response process interviews were conducted at Institution 1 with seven PC/BPC students approximately 2−3 weeks after administration. The purpose of these interviews was to ensure that students were properly interpreting the questions and that they were selecting the right answer for the right reasons.[45] If one or both of these conditions were not met, then the item was

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