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## 'Evaluating Students' Conceptual Understanding of Balanced Equations and Stoichiometric Ratios Using a Particulate Drawing

This study, which was published in the *Journal of Chemical Education* (1), was based on a multiple-choice question written in 1987 by Nurrenbern and Pickering (2), in which students were asked to choose the balanced equation for a picture showing the particles in a container before and after a reaction has occurred (Figure 1- Managing Editor's note: We are working on adding this figure). The most common but incorrect choice, option (d), is not as good as the correct answer, option (c), because it contains excess (unreacted) chemicals in it. Many students in my college chemistry courses have argued that (d) is a correct option, even though it suggests a reacting ratio of 3X:8Y instead of the correct 1X:2Y.

The research question investigated in this study was: ‘Do students who leave excess chemicals in a balanced equation use the correct reacting ratio when performing stoichiometry calculations?’ Ultimately, I was testing whether students understood what a balanced equation tells them (the reacting ratios of chemicals). The main theoretical framework used in this research is the Think-Aloud method, which assumes that students can monitor and report on their thought processes while solving problems (3). Although the Think-Aloud method was originally designed for oral interviews, this study used the Think-Aloud method for students’ written responses.

All students enrolled in the first-semester general chemistry course in Spring 2003 at MTSU were asked to participate ($N$ = 156). They were asked to answer a three-part question as part of an assigned in-class quiz: (1) Write a balanced equation for the picture in Figure 1; (2) Calculate the mass of the carbon-sulfur compound produced from 75.0 grams of carbon; and (3) Calculate the mass of sulfur needed to react with 33.0 grams of carbon. The question was changed from the generic X and Y atoms to carbon (C) and sulfur (S), respectively, because students needed to use the molar masses of actual reactants. The first step of the data analysis was to place students’ responses into categories based on their balanced equation from Part 1. The question in Part 2 was used to test for students’ stoichiometry ability: Responses to Part 3 were not evaluated if the student did not provide a proper set-up for Part 2. For Part 3, responses from students who left unreacted chemicals in their balanced equation were evaluated to see whether they used the correct reacting ratio for C and S.

From Part 1, several incorrect balanced equations were identified. In most of these, students showed confusion between the concepts of subscripts and coefficients (‘subscripts’ tell you how many atoms are in a single molecule, ‘coefficients’ tell you how many independent molecules you have). No student provided a balanced equation consistent with options (a), (b), and (e) from Nurrenbern and Pickering's question. Two other equations, '$X_3 + Y_8 \rightarrow 3XY_2 + Y_2$' and '$X_3 + Y_8 \rightarrow (XY_2)_3 + Y_2$', were suggested as better choices for this question. From Part 2, it was discovered that students who properly assigned subscripts and coefficients also performed better on the stoichiometry calculations. Of the 46 students who left unreacted chemicals in their balanced equation, only 23% used the correct reacting ratio of 1C:2S in Part 3; 64% used an incorrect stoichiometric ratio directly from their equation. This implied that these students did not understand that the excess chemical was not necessary for this reaction to occur.

(References appear at the bottom of the Reflective Essay.)

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