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Activity

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A Hands-On Activity Incorporating the Threefold Representation on Limiting Reactant

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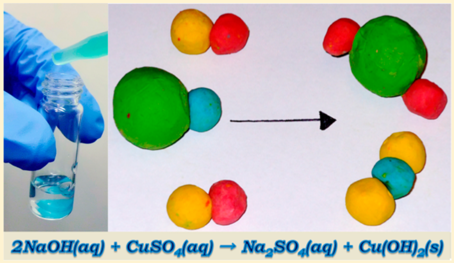
Supporting Information

ABSTRACT: Many students share the common belief that the limiting reactant in a chemical reaction is the reactant in the smallest quantity of material. To help students overcome this difficulty a hands-on activity for the limiting reactant concept was developed. The activity incorporates the three levels of representation (macroscopic, submicroscopic, and symbolic) and allows students to make connections among them by directly working at three stations. Each station incorporates one level of representation allowing students to explore one level of representation at a time. The focus of the activity is to help students understand thoroughly the topic of limiting reactant, including concepts related to it, such as reaction stoichiometry.



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The limiting reactant "is the reactant that is exhausted first"[1] during a chemical reaction. This happens because chemicals react according to fixed mole ratios; in other words, they react stoichiometrically.[2] Thus, the limiting reactant prevents the reaction from proceeding further[2] and limits the quantity of product that can be formed.[3] Many general chemistry textbooks and instructors introduce the concept of limiting reactant with appealing and familiar examples to attract students' attention, for example, the preparation of a pizza using different ingredients.[2] However, limiting reactant is a more complex concept and many students have difficulties with the topic, including selecting the limiting reactant arbitrarily,[4] having the inability to determine the limiting reactant when one of the reagents is in excess,[5] and indicating that the limiting reactant is the reagent that has the smallest stoichiometric coefficient or is in the smallest quantity of material.[5]

To help students understand the concept of limiting reactant, Tóth[6] introduced an analogy that consists in using teams of students for a competition. The analogy was followed by a chemistry example involving mole quantities and, finally, presenting a situation starting with the mass of the reactants in grams. In another work, Sostarecz and Sostarecz[1] introduced a conceptual approach that incorporates a visual representation through the use of graphs to determine the limiting reactant in a reaction. In a different investigation, Nakhleh and Postek[7] used the concept of limiting reactant to study the impact that the use of multiple representations had on students' learning. The study incorporated the use of the Synchronized Multiple Visualizations of Chemistry (SMV Chem) computer program, which allowed students to explore different external representations in any order or combination. The topic was chosen because it "provided students with many opportunities to explore the macroscopic, microscopic, symbolic, and mathematical levels in developing their understanding of the chemistry".[7]

Johnstone[8−11] has recognized the importance of the macroscopic, submicroscopic, and symbolic levels of representation in learning chemistry. In fact, it has being suggested[12−15] that one of the main reasons for students' difficulties with chemistry concepts is their lack of representational competence. In addition, Treagust and Chandrasegaran[16] suggest that the correct use of representations should be emphasized more in instruction and that students should be given the opportunity to work with chemical reactions themselves as well as to discuss the observations with their peers. Also, Chandrasegaran and Treagust[17] found that students obtained more meaningful learning about chemical representations when the instruction is focused on the three levels of representation. Finally, preliminary results[18] obtained by Ortiz-Nieves et al. suggest that instruction incorporating the threefold representation on redox reactions helps students improve their understanding of some concepts involved in the topic.

We developed an activity that incorporates Johnstone's[8−11] three levels of representation, using a hands-on approach, to help students obtain a better understanding of the limiting reactant concept while increasing their representational competence. A hands-on activity that incorporates the macroscopic, submicroscopic, and symbolic levels of representation for the redox concept has been published in this *Journal*.[19]

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■ ABOUT THE ACTIVITY

This article introduces an activity to help students develop a deeper understanding of the concept of limiting reactant at three levels of representation: macroscopic, submicroscopic, and symbolic. During the activity, students work in groups to explore the reaction of $CuSO_4$ with NaOH, one representation at a time, using a hands-on approach. The activity also facilitates the development of students' representational competence on the topic of limiting reactant.

This activity aims to overcome two common difficulties that students have (1) not being able to establish connections between the submicroscopic representation of a chemical reaction and the macroscopic observations[20,21] and (2) identifying the reactant in the smallest amount of matter as the limiting reactant.[1,22] To address these difficulties, students explored the reaction of $CuSO_4$ with NaOH at the macroscopic, submicroscopic, and symbolic levels of representation.

The activity was focused on exploring, gathering, and analyzing information to determine the limiting reactant for a particular reaction. Students worked on each representation one at a time to build a strong foundation at each level and then were guided to establish connections between the representations to hone their understanding.

Students were divided into small groups of three or four members. Groups worked on the representations in parallel; thus, they had a separate working space and their own set of materials. This allowed students to return to their work, if necessary. In addition, Johnstone[23] recommends introducing a topic with the more familiar representation. Thus, students began by exploring the macroscopic depiction, followed by the submicroscopic and the symbolic representations. Working on the first two representations consecutively helped students to start building a connection between those descriptions.

During each part of the activity, students were guided to determine the limiting reactant for the reaction. After spending about 20 min working on each part, students proceeded to answer a set of wrap-up questions and transfer problems that allowed them to connect the information obtained at each depiction. This allowed students to establish further conclusions based on the knowledge developed working with the reaction of $CuSO_4$ with NaOH at the three levels of representation.

To maximize the time spent on the activity, we divided the working space for each group into three sections labeled "Macroscopic Station", "Submicroscopic Station", and "Symbolic Station". Materials were distributed among their corresponding sections in as organized a manner as possible. For the macroscopic representation each group needed 14.00 mL of 1 M $CuSO_4{\cdot}5H_2O$ solution, 10.00 mL of 1 M NaOH solution, and 9.00 mL of 3 M NaOH solution. The solutions can be bought in volumes of 500 or 1000 mL for less than $10.00 each. To help students focus on the analysis of the activity, those solutions were prepared and measured beforehand. Each group carried out reactions inside two 25 mL test tubes labeled "Reaction 1" and "Reaction 2". To perform tests to determine the limiting reactants of the reactions, each group needed three droppers, two 0.5 mL pipettes (or droppers), and four vials (or small test tubes) labeled "Reaction 1—Test 1", "Reaction 1—Test 2", "Reaction 2—Test 1", and "Reaction 2—Test 2". In the submicroscopic station, the species involved in the reactions were represented using play dough balls of five different colors. The balls were constructed based on the relative atomic radii of the species (see the Supporting Information). To emphasize the state of matter of the species, and thus making a connection with the macroscopic description, the play dough balls were placed inside four 500 mL beakers (or comparative size containers). Lastly, in the symbolic representation students used data collected in the other two parts to construct the molecular equation for the reaction of $CuSO_4$ with NaOH. In addition, students completed a table that guided them in the determination of moles of product formed based on the limiting reactant. A description for each part of the activity follows.

Macroscopic Station

Students began their work at the macroscopic representation. Each group carried out two reactions of $CuSO_4$ with NaOH with different initial volumes. In one reaction the volume of $CuSO_4$ was smaller and in the other the volume was larger than the volume of NaOH. This distribution helped students understand the relationship between the initial quantities of material of the reactants and the limiting reagents. The reactions were left to proceed for about 3 min to obtain two distinct phases, the blue $Cu(OH)_2$ precipitate and the unreacted NaOH and Na_2SO_4 colorless liquid solution. Care was taken to ensure that a significant volume of the liquid solution forms at the top (Figure 1). Two aliquots of the supernatant of each reaction were then transferred to the four vials. To identify the limiting reactant in each reaction several drops of each reactant were added to the corresponding vials. Students observed that the blue $Cu(OH)_2$ precipitate formed in the vials where drops of $CuSO_4$ were added (Figure 2), indicating that copper(II) sulfate was the limiting reactant in both reactions. Meanwhile, nothing happened when the NaOH solution was added to the other two vials. The most important

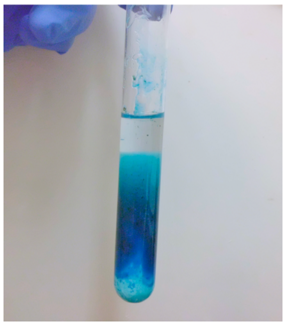

Figure 1. Precipitate and supernatant formed at the macroscopic station.

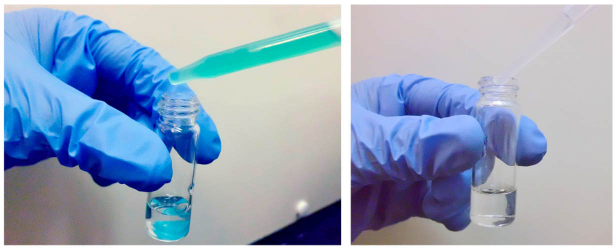

Figure 2. (Left) Formation of precipitate when drops of the limiting reactant $CuSO_4{\cdot}5H_2O$ are added in the first vial from reaction 1. (Right) No reaction occurs when drops of NaOH are added in the second vial from reaction 1.

conclusion that students drew from this part of the activity was that the limiting reactant is not always the one in the smallest quantity of material. Because this is a common alternative conception, the results could have generated cognitive dissonance in the students creating more curiosity and motivation for them to continue working on the activity.

Submicroscopic Station

To help students develop a connection between the macroscopic and the particulate levels of representation, students then proceeded to work on the submicroscopic station. Each group had four beakers with play dough balls that represented the unmixed reactants of the two reactions carried out in the previous station. The species represented by the balls were Cu^{2+}, SO_4^{2-}, Na^+, OH^-, and water molecules. The number of species provided to the students was equivalent to the stoichiometry of the reactants in the chemical reaction. Students were guided to form as much product as possible for each reaction, given the number of balls provided. Once the groups completed the process of forming the products, they analyzed their results to determine the limiting reactant for each reaction. Students were able to construct the stoichiometric ratio of the reaction of $CuSO_4$ with NaOH to produce $Cu(OH)_2$ and Na_2SO_4, and concluded that copper(II) sulfate was the limiting reactant in both reactions because it was consumed completely. At this point, many students started making connections between the macroscopic and submicroscopic representation, and some started to realize the importance of stoichiometry over the initial quantities of material when determining the limiting reactant in a reaction.

The main purpose of the model developed for the submicroscopic station was for students to identify the limiting reactant and to obtain the stoichiometric coefficients of the molecular equation. Thus, the model emphasizes on the chemical formulas of the reactants. There are two limitations of the model. First, the aqueous products were constructed as compounds, for example Na_2SO_4 and not as two sodium ions and one sulfate ion for each formula unit. This facilitated the determination of the stoichiometric coefficients. Second, the number of water molecules used is much less than in the actual solution. This facilitated the preparation of the species required in the station. Suggestions to address these limitations are given in the instructors' guide available in the online Supporting Information.

Symbolic Station

Most teaching on the topic of limiting reactant focuses on mathematical procedures. Thus, in this part of the activity most students relied on their calculations to verify the results obtained in the previous parts. In this representation, students gathered information from the macroscopic and submicroscopic stations to construct the molecular equation for the reaction of copper(II) sulfate with sodium hydroxide. The purpose of this strategy was to direct students to establish connections between representations. Each group was provided the volume of reactants used in each reaction carried out in the macroscopic station. Students used the volumes and the concentrations of the solutions to obtain the moles of reactants. They used this information about the moles of reactants for each reaction and the stoichiometry of the reaction to identify the limiting reactant of each reaction and obtain the moles formed of the precipitate $Cu(OH)_2$.

Wrap-Up

At the end of the activity students focused on a set of wrap-up questions and transfer problems that helped them summarize the results of their work, establish connections between the levels of representation, and apply the knowledge that they developed during the activity to answer similar, but novel, problems related to the concept of limiting reactant.

■ HAZARDS

While performing this activity, students should follow all the standard safety lab rules, such as the use of gloves, safety goggles, and a lab coat. The contact of skin or eyes with reactants, as well as ingestion and prolonged inhalation of these should be avoided. After the activity, the solutions should be collected and discarded following local disposal regulations.

■ INTEGRATING THE ACTIVITY INTO THE CURRICULUM

This activity integrates the three levels of representation on the topic of limiting reactant and is suitable for high school students and college students enrolled in introductory chemistry courses. Basic knowledge of the concepts of limiting reactant and reaction stoichiometry is recommended prior to the implementation of the activity. Thus, it can be conducted after the limiting reactant topic has been discussed in class.

In a high school environment, the topic can be divided into three separate class meetings. In the first meeting the teacher can introduce the limiting reactant concept using analogies (e.g., making a sandwich with different ingredients, stacking papers of different colors, etc.). The second meeting incorporates the activity to reinforce the concept. Finally, the third meeting can be used to review the activity and further the concept with examples of different reactions, in which the students have to apply the three representations to provide explanations of the chemistry of the reactions.

In college, typical laboratory activities involve determining the limiting reactant in a reaction qualitatively and numerically. The activity discussed in this article incorporates those tasks with a more pedagogic approach, expands on the submicroscopic aspect, and focus on the interrelation of the three representations to enhance students' comprehension of the topic. Thus, the activity can be used to replace a typical laboratory activity on the topic of limiting reactant.

■ ASSOCIATED CONTENT

Ⓢ Supporting Information

Student activity worksheet; instructor information and answers to questions. This contains the instructions and questions that will guide students through the activity. In addition, answers to the wrap-up questions are provided for the instructors. This material is available via the Internet at http://pubs.acs.org.

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Notes

The authors declare no competing financial interest.

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