Teaching Chemical Equilibrium using a Macro Level Analogy

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CHEMICAL CONCEPTS

Chemical Equilibrium

Forward and reverse chemical reactions
Simultaneity of rates of forward and traverse chemical reactions
Dynamic nature of chemical equilibrium
Equilibrium position
Equilibrium process

Cognitive Skills

- Construction of a mental model of chemical equilibrium
- Using the mental model to predict outcomes of chemical equilibrium experiments.

HOW THE DEMONSTRATION ADDRESSES THE CONCEPTS

The function of an effective demonstration is to facilitate the construction of a mental model of a chemical concept in the mind of a learner. The abstract nature of much of the domain of chemistry presents an opportunity to use demonstrations to teach chemical concepts. In teaching chemical equilibrium, a simple set of demonstrations has been developed that can help learners construct a mental model of the concept of chemical equilibrium.

I take as my theoretical perspective mental model building as learning (Briggs & Bodner, 2005; Briggs, 2006). Mental model building is a paradigm that proposes an explanatory metaphor for the process of learning and is congruent with constructivism. In order to construct a domain acceptable mental model of a phenomenon, a demonstration must facilitate students' knowledge construction (in order to avoid misconceptions). In this paper I will give constituents of a mental model and show how to use those constituents to facilitate the construction of a mental model of equilibrium.

I will use the same lesson plan I use in my lectures to introduce a demonstration of the macro level analogy to molecular level chemical equilibrium. I will introduce the constituents of a mental model and point out the comparison between the molecular and macro level analogy.

A mental model of a chemical concept consists of five constituents. Four of the constituents are static and one of them is dynamic. I present the static constituents first.

The first constituent is "referents." I take referents to be the vocabulary of a concept. Importantly, referents point to objects, either physical or mental. For example, in chemical equilibrium some referents are forward reaction, reverse reaction, rate of reaction, simultaneous, equilibrium process, double arrows, concentration, equilibrium position, and catalyst effect.

The second constituent of a mental model of chemical equilibrium is "rules/syntax". In chemistry one writes a forward chemical reaction equation with the reactants on the left and the products on the right. This syntax is basic to understanding chemical reactions. Our rules for naming compounds and determining R–, S–notation are examples of the importance of rules and syntax in our mental models. Some rules/syntax for chemical equilibrium are simultaneous and reaction equation.

The third static constituent is "relations". The constituents of a mental model mirror the connections between mental objects in a concept and the connections between physical objects in the world. To help a student construct an acceptable mental model one must demonstrate the relationships between the constituents and the objects. Concept maps were an early activity to address this point (Novak, 1998). Some relations in chemical equilibrium are: reactants form products, "products" form "reactants" (the reverse reaction), and original reactants are reformed. There is also a relationship between the rates of the forward and reverse reactions.

The fourth constituent is "results". This constituent is the consequence of using rules and syntax to apply an operation upon referents and their relations. An important aspect of learning is to be able to use a mental model to predict results. Some results in a mental model of chemical equilibrium are equilibrium position and disequilibrium (Le Chatelier's principle).

The fifth constituent is dynamic: "operation". The operation is the core of a mental model of chemical equilibrium. I call this operation the Equilibrium Process.

PREPARING THE DEMONSTRATION

Equipment and materials

- 2 600 mL beakers or equivalent
- 2 250 mL beakers or equivalent
- 2 100 mL beakers or equivalent

- 2 plastic rulers
- 2 Dish washing tubs

- 1 data display device or paper template forms

- 20 to 30 liters of water and a place to dispose of the water
- 2 different colored food grade dyes

Safety

- Use non–breakable beakers, tubs, and rulers
  - Some possibilities are cut off plastic beverage bottles
- Perform the demonstration on a water proof surface
  - Have absorbent media ready for splashes and spills
- Use food grade dyes to color the water

Set up

- Place the two dish washing tubs on a level surface and place about 5 liters of water into one and 8 liters into the other.
- Color each tub with a different color dye.
- Select volunteers for each of the positions
  - Forward dipper
  - Reverse dipper
  - Forward depth measurer
  - Reverse depth measurer
  - Data scribe(s)
  - Cadence caller
- Place the dippers on opposite sides of the table with the two tubs between them.
- Place the measurers near the dippers
- Place the cadence caller at one end of the table so the dippers can hear the cadence.
- Place the data scribe(s) near the data collection screen, blackboard, or whiteboard.

PEDAGOGY OF THE DEMONSTRATION: SIGHTS AND SOUNDS

In order for students to construct mental models of chemical concepts, they need help in identifying the constituents of specific mental models. With experience, metacognition, and sound scaffolding they can then begin to construct their own domain acceptable mental models of chemical concepts taught in the classroom. These demonstrations of chemical equilibrium are a method of teaching students to construct their own mental models.

Demo 1. Establishing an equilibrium position

a. Use a 600 mL beaker in tub #1 and a 600 ml beaker in tub #2. Take a measure of the water depth in each tub after the water settles.

Point out the referents of the chemical equilibrium mental model. The two tubs represent the reactants of the chemical reactions; tub #1 is the forward reaction and tub #2 is the reverse reaction. The sizes of the beakers represent the rates of the two reactions. The measurements represent the progress of the reaction toward the equilibrium position. To illustrate this point, the measurements could be made more frequently and plotted to show how they tend toward the equilibrium point.

b. As the cadence caller counts each transfer of water, s*imultaneously* use a 600 mL beaker to dip into tub #1 and pour the contents of the beaker into tub #2 and dip another 600 mL beaker into tub #2 and pour its contents into tub #1.

Point out the simultaneous transfer of water that represents the chemical reactions taking place. Point out the color change taking place which represents the increase of or decrease of reactants of the two chemical reactions. The color change illustrates the changing relation (concentration) between the reactants of tub #1 and tub #2.
Also point out the relationship between the two beakers at one cadence count. This represents the simultaneity of the two chemical reactions. Note that this is a rule of equilibrium which we put into the syntax of a chemical equation with double arrows.

c. The cadence caller should count about one transfer per second. Be sure that the dippers work in a synchronized manner. Dip for about 20 transfers.

Point out the time or number of transfers required to reach the equilibrium position.

d. Let the water settle and measure the depth of the water in each tub.

Note that the depth of water in each tub represents the concentration of reactants and indicates the equilibrium position of the two reactions. Tell the students that the constant depth of water represents the equilibrium position. This is why we have to make multiple transfers of water in order to reach the equilibrium position.

e. Resume the water transfer for another 10 transfers and take another set of water depth measurements. Compare the measurements and note if they are different from the first set of measurements. This may indicate that the equilibrium position has not yet been established.

f. If necessary, repeat the water transfer for another 10 transfers and take another set of measurements of the water depth. Compare the water depths to the previous measurements. If the last measurements are within 3 to 5 % of the previous measurements, then the equilibrium may be said to have been established. Note also the color of the water. It should be the same in both tubs.

Point out that the equilibrium position has been reached using the 600 mL beakers. Point out the levels of water in the two tubs and state that this is the equilibrium position for the specific reaction trial (600 mL beakers). The levels of water should be about the same in each tub if no water has been lost to splashes.

g. Ask students to identify the reactions (red water and blue water). "*What represents things at the molecular level?*" Ask them to identify the rates of the reactions (the sizes of the beakers). Ask them to explain when the reactions reached equilibrium (the water depths remained constant and the colors in each tub were the same).

h. Review:

- referents: dynamic nature of equilibrium; water transfer between tubs; two reactions occurring: two beakers transferring water; reactions occurring at the same time: synchronicity of water transfer; a forward and a reverse reaction: transfer of water from tub #1 to tub #2 and transfer of water from tub #2 to tub #1; the use of the double arrow to indicate equilibrium reactions)
- rules/syntax: forward reaction, from tub #1 to tub #2; reverse reaction, from tub #2 to tub #1)
- Relations: reactions; transfer of water from one tub to another tub
- Results: equilibrium position; constant value of the water depths; water color
- Operation: dynamic process resulting in the equilibrium position; constant water depths

Demo 2. Effect of a fast forward reaction rate on equilibrium position

Refill the tubs, about equally, with colored water. Follow points a through h for demo 2 but make the following changes.

Use a 600 mL beaker and a 250 mL beaker. The different sized beakers will lead to a different equilibrium position, that is, different constant depths of water in the two tubs. This represents a fast reaction (600mL beaker) in one direction and a slow reaction (250 mL beaker) in the reverse direction.

Be sure to point out the constituents of a mental model to reinforce student learning.

Demo 3. Effect of a fast reverse reaction rate on equilibrium position

Refill the tubs with colored water about equally. Follow points a through h for demo 2 but make the following changes.

Use a 100 mL beaker and a 600 mL beaker. The different sized beakers will lead to a different equilibrium position, that is, different constant depths of water in the two tubs. This represents a fast reverse reaction (600mL beaker) in one direction and a slow reaction (250 mL beaker) in the forward direction.

Be sure to point out the constituents of a mental model to reinforce student learning.

Demo 4. Catalyst effects on equilibrium position

Refill the tubs with about 5 and 8 liters of water and add colored food dye . Follow points a through h for demo 2 but make the following changes. In this demonstration one can show that a catalyst does not change the equilibrium position but allows the two reactions to reach the equilibrium position more quickly. Caution: students may get carried away with this demonstration and splash water out of the tubs !

Have the cadence counter call out the water transfers at the rate of about three a second. Time the interval to reach the equilibrium position. Compare the time to reach equilibrium using a fast cadence with the time in Demo 1. Point out that the same water levels are reached at the equilibrium position but were achieved in a shorter time. Point out that the faster cadence represents the action of a catalyst in an equilibrium reaction.

There may be other possibilities for using these demonstrations of chemical equilibrium. Please feel free to experiment with these demonstrations and let me know how you use it in your classes. Post your comments to the ChemEd list at
http://jchemed.chem.wisc.edu/ChemEd/ChemEdL/index.html

or to me directly at m.w.briggs@iup.edu.