Teaching with Problems in the Sciences

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"The crucial indicator of a student's understanding of a concept, a principle, or a procedure is that he [or she] is able to apply it in circumstances that are different from those under which it was taught. Transferability is the key feature of meaningful learning. So if we are to test for understanding, we must test in circumstances which are at least part new."
R. L. Thorndike, *NCME Measurement in Education*, **1** (1), 1-4 (1969)

"By the time students are in the upper grade levels or in college, there is a good case for arguing that factual knowledge should be subsumed under higher level objectives, so that students are expected to use factual knowledge in solving a problem or carrying out a process, but are not tested directly on their ability to recall the information."
T. J. Crooks, *Review of Educational Research*, **58** (4), 438-481 (1988)

Most common student complaint in science courses:

"I knew all the course material! How could I have done so poorly on the exam?"

Bloom's well-known taxonomy of cognition:
B. S. Bloom, *A taxonomy of educational objectives*. New York: Longman (1956)

- Knowledge
- Comprehension
- Application
- Analysis
- Synthesis
- Evaluation

A more practical 3-level taxonomy:

- **Facts**: Simple recall or recognition of factual information.

- **Understanding**: Comprehension, description, explanation of theories and concepts.

- **Problem-Solving**: Using facts/understanding to solve problems,
 especially problems unlike any encountered before.

Pourbaix diagram Activity

Shown below is a *Pourbaix diagram* for manganese (Mn) in aqueous solution. Here are the important **facts** about such diagrams:

- The *x*-axis represents pH, with low numbers representing acidic solutions and high numbers representing basic solutions. (A neutral solution will have pH=7.)
- The *y*-axis represents the oxidizing potential E (in volts) of the solution. High numbers represent a very oxidizing environment (for example, water exposed to oxygen in the atmosphere) while low numbers represent a reducing environment.
- For each manganese-containing species, there is a certain region of pH and E where that species is the thermodynamically most stable species. These regions are indicated on the diagram.
- The indication (s) means that the species is a solid precipitate. Other species are dissolved in water.
- Water is stable only in the region between the two broken diagonal lines.
- For each manganese-containing species, an *oxidation state* can be assigned to Mn using the rules that oxygen (O) is –2, hydrogen (H) is +1, and the sum of the oxidation states must equal the overall charge on the species. For example, in MnO_4^-, the Mn is in the +7 oxidation state.
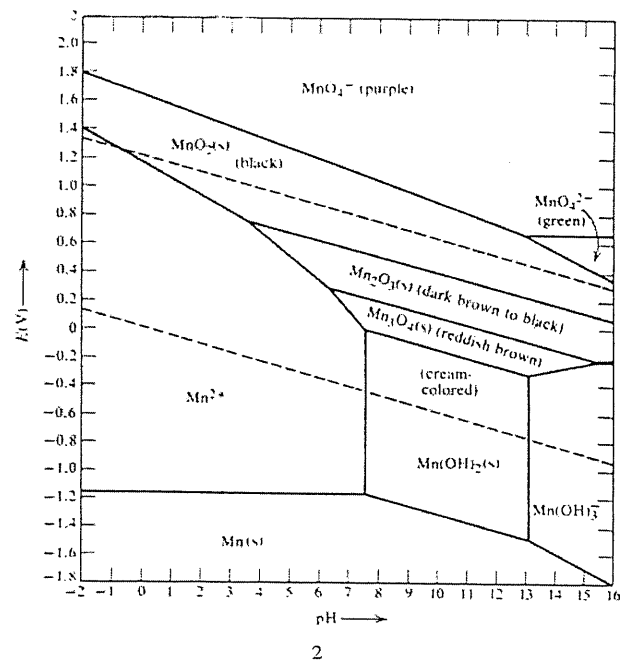
What **types** of questions can we ask about Pourbaix diagrams?

• **Discussion Questions** are didactic, with a focus on understanding/comprehension.

Example: Explain the significance of each of the following types of borders on the Pourbaix diagram:
  a) Borders that are *strictly vertical*.
  b) Borders that are *strictly horizontal*.
  c) Borders that are *diagonal*.

• **Practice Problems** are simple "exercises" that test facts and simple problem-solving skills.

Example: What manganese-containing species are stable in water at pH=1? Assign oxidation states to all the atoms in each of these species.

• **Problem Set Questions** are more involved, and test more advanced problem-solving skills. (The toughest problem set questions should be **more challenging** than any exam questions.)

Example: You wish to use $KMnO_4$ as an oxidizing agent. What conditions should you use in order to avoid the formation of a solid precipitate? Explain your answer.

• **Exam Questions** require students to apply problem-solving skills in *new* situations.

Example:
Here is the Pourbaix diagram for iron (Fe). (Here, species that are dissolved in water are explicitly noted by (aq).)

At the beginning of life on Earth, the environment was a reducing environment (low E). Later, photosynthetic plants released oxygen into the atmosphere, transforming our environment into an oxidizing environment (high E). One of the most significant biological effects of this change was that the availability of soluble iron was drastically reduced. Explain why by analyzing the above Pourbaix diagram for iron.

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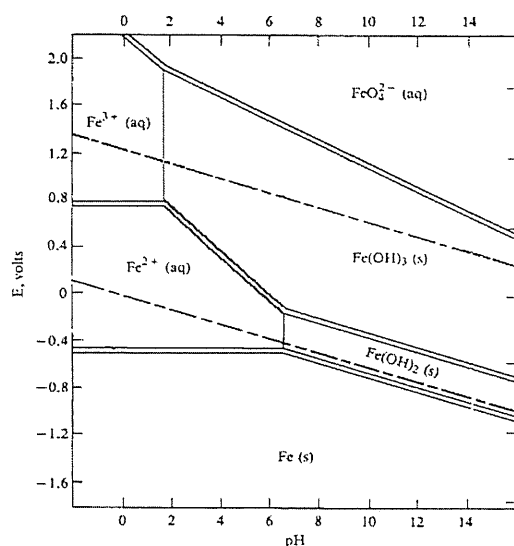
How can we **incorporate** these types of questions into our **teaching**?

• Add questions into your outline for discussion section

Objective 1: Understand how mutations can arise, and how beneficial ones can alter populations

➢ Mutation= a randomly produced, heritable change in the nucleotide sequence of a genome
➢ Three types of mutations-neutral, deleterious, and beneficial

The key to emphasize here is that mutations occur randomly and that the mutation can either be neutral, beneficial, or deleterious to the organism. When deciding whether a mutation is deleterious, beneficial, or neutral you should consider the perspective of the organism that develops the mutation.

Consider the following situation of bacteria and antibiotic resistance: If a patient is taking an antibiotic to clear an infection and they do not properly take their medication, a single bacterial cell can develop a mutation that confers resistance to this antibiotic.
Is this mutation beneficial to the bacterium? Yes To the patient? No
Can this single bacterium change the outcome of the infection in the patient? Yes, this
beneficial mutation will be able to reproduce. It will produce more prodigy than the antibiotic sensitive bacteria (be selected for) and will eventually take over the population. The infection will no longer be amenable to treatment with the antibiotic.

• Set aside time for problem solving during section

Discussion Week 8

1. You decide to design an experiment so you can witness evolution in action. You choose bacteria for your experiment since they divide every twenty minutes. You will treat the bacteria with vancomycin, an antibiotic that inhibits the synthesis of bacterial cell walls, and see if the bacteria develop resistance to vancomycin.

   First you pick a single colony of wild type bacteria from a plate and grow the bacteria in a culture (Culture A) containing 10 milliliters of media overnight. You also pick a second colony of wild type bacteria and grow this bacterial colony in 10 milliliters of media containing vancomycin overnight (Culture B). In the morning, you take 10 microliters (1/1000th) of each culture and spread the 10 μl sample on a plate with media and a second 10 μl sample on a plate with media plus vancomycin. You incubate the plate overnight and count the colonies the next day.

Bacterial Colony grown in 10 ml culture	#colonies on minimal media plate	#colonies on minimal media plate + vancomycin
Culture A: Media	1000	1
Culture B: Media +Vancomycin	205	200

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