In-class exercise 1: Representations of reality
As mentioned in Suzanne Langer’s article, humans use symbols as ways of conceiving representations of reality. A model is one such way that a symbol shows up in science; “model” is often used to describe a theory that will generate concrete, measurable results. Thus, evolution is a theory because it is difficult to predict what organisms will result from its processes in the future; however, we can develop climate models, and predict when the next Ice Age will be coming, or what global warming will do to Seattle’s temperatures in the next century.

In this assignment, you will look at a couple of different models: John Dalton’s atomic theory and Linus Pauling’s chemical bond model. While examining the models, I hope you see that models are useful, not only because they can predict system behavior, but also because they can suggest analogies that might lead to a greater understanding of the theory behind the model. In this way, models are representations; like all representations, they can be powerful, but they are also need to be limited in how they are used.

**Procedure:**
Break up into groups of four to five. Obtain from the cart:

- a molecular model kit
- a ringstand with crossbar
- a tuning fork
- a wide brass spring
- a narrow brass spring
- a steel spring
- three weights on hooks — 200 grams, 100 grams and 50 grams (you may have to share with another group)
- a stopwatch

*Atomic theory* (you’ll need the molecular model kit)

John Dalton in 1800 published a paper laying out atomic theory. In a nutshell, he echoed an earlier classical Greek idea of atoms being the fundamental unit of matter, but he went further and suggested that atoms in substances occurred in groupings (which we call molecules) that contained simple whole number ratios of different atoms.

For instance, a water molecule comprises two hydrogen atoms for every oxygen atom so there’s a 2:1 ratio of hydrogen atoms to oxygen atoms in any amount of water.

Here is the simplest level of representation: **symbols**. Clearly, atoms are too small to be seen by the unaided human eye, so in order to grasp (literally) the
idea of atoms and molecules, the traditional representation has been to use wooden or plastic balls for atoms and sticks for chemical bonds. Dalton’s atomic theory can be simplified by the rules below.

The rules:
- Yellow represents **hydrogen**
- Red represents **oxygen**
- Black represents **carbon**
- Blue represents **nitrogen** (some of these blue balls have five holes but use only three adjacent holes)
- Sticks and springs represent chemical bonds (which are merely a pair of shared electrons between atoms); length doesn’t matter
- For a molecule to be "happy" (i.e., have all of its bonding requirements satisfied), all holes must be filled with bonds

1. Thus a nitrogen atom can only bond to three other atoms maximum. What is the maximum number of atoms that **carbon** could bond to (hint: count holes)? That **oxygen** could bond to? That **hydrogen** could bond to?

2. Create the following molecules: water (H₂O), ammonia (NH₃) and methane (CH₄), then draw the molecules. Try to use shading and perspective to give a three-dimensional feel for each molecule.

3. Go to the next level of abstraction: convert the balls in the drawings above to **letter symbols** for each atom (H = hydrogen, C = carbon, N = nitrogen, O = oxygen) and convert the sticks into **simple lines** connecting the symbols.

4. What information have you **lost** as a result of the conversion to symbols? What information have you **gained** as a result of the conversion?

5. Chemists go one step further in abstraction and write chemical formulas for each molecule: water becomes H₂O, ammonia becomes NH₃, and methane becomes
What information have you lost as a result of the total conversion to symbols? What information have you gained as a result of the total conversion?

6. Create the molecule CO\(_2\) (carbon dioxide). What type of bonds need to be used to fulfill the "fill every hole rule"? And is there more than one legal way to do this? The correct structure will not have any oxygen-oxygen bonds.

Some more rules: A bond (either a stick or a spring) represents two electrons shared between two adjacent atoms. Suppose you have two sets of bonded atoms A-B and C-D. The bond between A and B is said to be equivalent to the bond between C and D if:

- A is the same element as C and B is the same element as D, and  
- the number of bonds between atoms A and B is the same as the number between atoms C and D

7. True or false (which illustrate the key difference between water and carbon dioxide):

The bonds in water are equivalent.

The bonds in carbon dioxide are equivalent.

The bonds in water are equivalent to the bonds in carbon dioxide.

8. Build a slightly more complex molecule: a simple amino acid called glycine, which has the chemical formula H\(_2\)NCH\(_2\)COOH (Hint: see the carbon atom on the right has a double bond to an oxygen atom). Do a “bond inventory” of glycine by filling in the following table:

<table>
<thead>
<tr>
<th>Bond type</th>
<th>N—H</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of equivalent bonds</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The model of the chemical bond (for this part, you will need the rest of the stuff).

Hang the steel spring from the crossbar of the ringstand and thread the 200 gram weight on the spring’s dangling end. Have someone work the stopwatch.

Pull the weight down a few centimeters (do not permanently stretch out the spring!) and have the timer determine the number of seconds it takes for the weight to complete 10 full cycles. A cycle is one complete up and down motion of the weight. Fill in the table below.

Repeat the measurement with the two other springs and the same 200 gram weight.

9. To calculate the frequency of each spring, take the 10 cycles of spring motion and divide by the time it took to complete 10 cycles in seconds; the resulting number is called the frequency and it is measured in cycles per second or Hertz (symbol: Hz) for short.

<table>
<thead>
<tr>
<th>Spring type</th>
<th>Steel spring</th>
<th>Wide brass spring</th>
<th>Narrow brass spring</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time it takes for 10 complete cycles (seconds)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frequency of the spring (Hz)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

10. Do the springs all have the same frequency or different frequencies? Suggest a reason this might be so.

11. Using only the wide brass spring, do the 10-cycle time measurement with the 50 gram and 100 gram weights, fill in the table below and calculate the frequency.

<table>
<thead>
<tr>
<th>Weight on the wide brass spring</th>
<th>200 g</th>
<th>100 g</th>
<th>50 g</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time it takes for 10 complete cycles (seconds)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frequency of the spring (Hz)</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

12. Using rough approximations, every time the weight was halved, what happened to the frequency? If this has a simple answer, you have a model.
Linus Pauling in 1927 noticed this behavior in molecules. He reasoned that, since the same behavior occurred in different molecules as occurred in different springs, that he could make an analogy between springs and chemical bonds in molecules. This would allow him to use the well-known physics and mathematics of spring behavior to predict the behavior of chemical bonds.

13. That’s nuts. After all, a chemical bond is not literally a spring between two atoms in a molecule. What is a chemical bond made of?

However, Pauling was not deterred by this observation, which had been made even before his time. He suggested that the chemical bond behaved like a spring because electromagnetism, the force holding the atom together, was also the force governing the material of the spring, so the analogy was not invalid. In fact, he went further and suggested that, like a spring, one could cause a chemical bond to vibrate faster or slower by aiming the same frequency energy at it.

Tap the tuning fork; note its pitch. Also listen to the sound coming out of the open end of the wooden base.

14. Choose the most vocally-talented American Idol in your group to match the pitch using voice only. Still the fork, then hum the pitch in the open end of the base. What do you notice happening at the fork? This is a phenomenon called resonance.

15. Still the fork again. This time, hum off-pitch. What do you notice happening at the tuning fork? Write a general rule about when resonance occurs (use phrases like “the source frequency” – in this case, someone’s voice – and “the frequency of the output device” – in this case, the tuning fork.

16. Given that chemical bonds can be modeled as springs, is it reasonable to suppose that a chemical bond has a characteristic frequency? If that is the case, would it possible for humans to “hum” a frequency that would excite (cause resonance in) the chemical bond “spring”?
Ultimately, the ability to cause resonance is related to the ability to transfer energy from one object to another; this often involves changing the form of the energy itself!

17. Show the conversion of different forms of energy (use a series of arrows) from the sound energy of the voice to the sound energy of the tuning fork.

18. Was the tuning fork sound as loud as the humming of the person? If not, where did the “extra” sound energy of the person’s voice go? Indicate this “loss” of energy in your model in question 17.

19. It turns out that light has a measurable frequency, too. And by light, I mean not only visible light, but infrared (IR) radiation (heat), ultraviolet (UV) radiation, X-rays, radio waves and so forth, all across the electromagnetic spectrum. Like you did in question 16. Show the conversion of sunlight energy into heat in our atmosphere at night. Please show where resonance occurs — in fact, it occurs a couple times.

20. In the previous question, you drew a model of how energy conversion occurs on the Earth’s surface. Describe at least three ways in which the model differs from reality. To put it another way, what factors does the simplification you drew above ignore? Clearly, to get a better model of the greenhouse effect, we would need to add in all of these factors to our model!