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UNIT LEVEL DQ: Why is a body temperature of 107°F deadly?

INVESTIGATION 1: How are interactions with water important for maintaining my life?

Overview

We have looked at how simple molecules interact with each other. In particular, for the last unit, we saw how the polar attractions between water molecules supply the energy to fuel a hurricane. Water is also essential for life. It participates in important chemical reactions and it helps shape the proteins that our DNA manufactures to do everything from transport oxygen, to fighting off disease. Much of the focus has been on interactions between polar molecules. In moving to a biological context we will look at how nonpolar attractions are also important in the formation of molecules that get their function from the particular shape they have formed. Students will look at how molecular interactions between large molecules and the water-based environment ubiquitous to life and how molecular interactions within the larger molecules themselves result in molecules with just the right shape to have a particular biological function. In the Investigation that follows students will explore why shape is important and how thermal energy levels are important to the stability of the molecular interactions.

The Performance Expectations (NGSS)

HS-PS3-5. Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.

Elements from NGSS (NGSS Lead States, 2013, p. 97–99)	**Connections to this investigation**
Elements of Disciplinary Core Idea	
Elements of the core idea from the NGSS Performance Expectation	How this investigation builds toward the core ideas

Relationship Between Energy and Forces: • When two objects interacting through a field change relative position, the energy stored in the field is changed.	Any charged object has electric field around it and the energy of the field depends on the amount of charge and position of the charges. When two charged objects interact the energy of the field changes depending on the arrangement of objects within the field. For example, when opposite charges are moved farther apart, the potential energy stored in the electric field between those charged objects is increased. In Unit 3, students analyzed energy changes associated with breaking chemical bonds with the energy changes associated with overcoming the interactions between molecules. In this investigation students will explore how energy changes when polar and nonpolar parts of large molecules interact with each other to help proteins and DNA maintain their three dimensional structure, which is essential for carrying out biological functions.
Crosscutting concept	
Crosscutting concept from the NGSS Performance Expectation	How this investigation builds toward the crosscutting concept
Cause and effect: • Cause and effect relationships can be suggested and predicted for complex natural and human designed systems by examining what is known about smaller-scale mechanisms within the system.	Forces between different parts of large molecules and interactions with water surrounding those molecules cause the molecules to form into particular shapes. Associated with the changes in shape are changes in the electric field generating those forces ans subsequent changes in in energy as the molecules arrange into structures that minimize potential energy.
Science and engineering practice	
Science and engineer practice from the NGSS Performance Expectation	How this investigation builds toward the science and engineering practice
Developing and Using Models: • Develop and use models based on evidence to illustrate the relationships between systems or between components of a system.	Students draw models and use simulations to explore what happens to atoms and molecules during various atomic and molecular rearrangements, how those rearrangements relate to changes in energy, and how those relationships can be used to explain observations.

HS-LS1-6. Construct and revise an explanation based on evidence for how carbon, hydrogen, and oxygen from sugar molecules may combine with other elements to form amino acids and/or other large carbon-based molecules. Clarification Statement: Emphasis is on using evidence from models and simulations to support explanations.

Elements from NGSS (NGSS Lead States, 2013, p. 97–98)	**Connections to this investigation**
Elements of Disciplinary Core Idea	
Elements of the core idea from the NGSS Performance Expectation	How this investigation builds toward the core ideas
Organization of Matter and energy Flow in Organisms: • The sugar molecules thus formed contain carbon, hydrogen, and oxygen; their hydrocarbon backbones are used to make amino acids and other carbon-based molecules that can be assembled into larger molecules (such as proteins or DNA) used, for example, to form new cells.	Proteins are made up of amino acids that can be classified as polar and nonpolar based on their atomic composition. Amino acids combine to form large protein molecules with a certain three dimensional arrangement. Interactions between polar parts of amino acids and nonpolar parts of amino acids help determine protein's shape and function.
Crosscutting concept	
Crosscutting concept from the NGSS Performance Expectation	How this investigation builds toward the crosscutting concept
Energy and Matter: • Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system.	Students explore the building blocks of organic molecules and see that carbon, oxygen, and hydrogen are the most common components of these molecules, including the amino acids used to make proteins. These atomic components are derived from the atoms in the food we eat.
Science and engineering practice	
Science and engineer practice from the NGSS Performance Expectation	How this investigation builds toward the science and engineering practice

Constructing explanations and designing solutions: • Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future.	Student will explore various 3D structures using interactive simulations to formulate explanations of how these structures are built from a small number of elements, the same elements found in sugar.contributes to producing stable three dimensional shape of the protein.

Objective: Target Model

What should the students' conceptual model include?

- *Polar and nonpolar molecules have different attractive forces.*
- *The different attractive forces between polar and nonpolar molecules affect how one substance dissolves or doesn't into another substance.*
- *Proteins are large molecules that have polar and nonpolar parts that can interact with each other and the surrounding molecules.*
- *The interactions within molecules and/or with other the molecules around them can cause specific structures to form.*
- *The resulting configurations result in lower potential energy for the entire system.*

Background Knowledge

Molecules interact with other molecules through intermolecular forces. Intermolecular forces in polar molecules are due to interactions between permanent partial charges. When the charge of interacting particles is stronger, the interaction between those particles is stronger. Intermolecular forces in nonpolar molecules are due to interactions between induced, temporary partial charges resulting from momentary uneven electron distribution due to electron motion. Since these forces are temporary and random, they are much weaker than more consistent polar interactions. As a result nonpolar molecules don't stick together as strongly as polar molecules, which is manifested in lower boiling points, lower viscosity and other properties.

Though the magnitude of polar and nonpolar interactions in intermolecular forces is smaller than in a bond, the forces and energy involved behave the same way as the forces that hold atoms together in bonds. When molecules are closer together, oppositely charged particles are closer, so the potential energy in the field between those particles is reduced. Separating molecules causes the charged particles to be moved farther apart, increasing the potential energy associated with the electric field.

Activities

Activity 1.1	*Why don't oil and water mix?*	*180 min.*
Activity 1.2	*Can a substance dissolve in both nonpolar and polar?*	*90 min.*
Activity 1.3	*What are proteins and how do they fold into biologically important shapes?*	*90 min.*

Activity 1.1: Why don't oil and water mix?

SUMMARY

In previous investigations students have primarily looked at pure substances. However, many things, including our own bodies are mixtures of many different substances. Water, making up a large percentage of our bodies, is almost always part of that mixture, so interactions with polar water molecules are important to the processes needed to live. Students have seen that polar molecules have a stronger attraction for each other than nonpolar molecules do. In this activity students will explore the ramifications of mixing substances with varying forces of attraction for each other as is seen when polar and nonpolar substances are combined. Through a hands-on activity and simulations students will explore solubility and characterize the forces and energy involved in the process. In later activities students will explore self-assembly and see how this applies to shaping proteins.

LEARNING GOAL

Students will formulate a scientific explanation of solubility using relative strengths of intermolecular interactions.

Disciplinary core idea	Crosscutting concept	Science and engineering practice
Relationship Between Energy and Forces: When two objects interacting through a field change relative position, the energy stored in the field is changed. (NGSS Lead States, p. 99)	*Cause and Effect* Cause and effect relationships can be suggested and predicted for complex natural and human designed systems by examining what is known about smaller-scale mechanisms within the system. (NGSS Appendix G, p. 83)	*Constructing explanations and designing solutions:* • Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. • Apply scientific ideas, principles, and/or evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects. • Apply scientific reasoning, theory, and/or models to link evidence to the claims to assess the extent to which the reasoning and data support the explanation or conclusion. (NGSS Appendix F p. 61)

POINTS FOR CONSIDERATION

- In this activity students will investigate the solubility of polar and nonpolar substances. Students may have heard a heuristic expression "like dissolves like" in other classes and might tend to give a surface level explanation using this principle when describing why polar substances dissolve in polar solvents and nonpolar substances dissolve in nonpolar

solvents. It is important to emphasize that they should provide justification for observed dissolving pattern that is grounded in ideas of forces and energy.
- All neutral molecules attract to each other, but they attract with different forces. Polar molecules attract to other polar molecules more strongly than they do to non-polar molecules. Because polar molecules have a stronger attraction for each other, a mixture of polar and nonpolar molecules will naturally separate from each other like oil and water do.
- As molecules attract to each other they change in position so that potential energy is minimized. This combination of attractive forces and energy minimization drives solubility (and other organizational structures at the molecular level).

PREPARATION

Class Time: 180 min.

Materials (for each group)
- Hands-on activity 1.1
  - Three petri dishes
  - Water: cold, room temperature, and hot
  - Sugar-rich candy (for example, M&M, red hots, etc.)
- Hands-on activity 1.2
  - 10 Test tubes for mixing substances (Note: You can use fewer test tubes. However, If test tubes are reused they need to be cleaned and dried before reuse.)
  - Test tube rack
  - Water
  - Hexane (or odorless mineral spirits)
  - Sugar
  - Iodine
  - Oil
  - Ethanol
  - Pipettes

Materials (for the whole-class demonstrations)

Boiling Eggs
- One beaker with room temperature water
- One beaker with hot (but not boiling) water
- Two eggs

Mixing Polar and Non-polar liquids
- One empty clear plastic water bottle with cap.
- Enough water to fill half of the bottle colored with food coloring
- Enough oil to fill the other half of the water bottle. (Or other non-polar liquid students have not seen mixed with water yet.)

Hand-out for hands-on activity 1.1

Hand-out for hands-on activity 1.2

Activity Setup

- Boiling Eggs Demo: Prepare two beakers: one with room temperature water and one with very hot, but not boiling water (at least 165 °F). The hot water should look similar to the room temperature water, no boiling should be visible. Crack one of the eggs open in front of students and separate egg white from the yolk. Put some egg white into each beaker and let students observe what happens.
- Mixing polar and nonpolar liquids demo: Fill the water bottle half full with water and add several drops of food coloring. Fill the remaining space in the bottle with oil or other non-polar liquid that students have not seen mixed with water before. Cap the bottle.
- Print handouts for each student for hands-on activity 1.1 and hands-on activity 1.2
- Mixing polar/nonpolar liquids: add food coloring to water and add the nonpolar liquid of choice

HOMEWORK

Reading for Activity 1.1: Why does salad dressing separate in the fridge?

SAFETY ISSUES

Hot plates are used in the teacher demo. Hot plates must be handled with care to avoiding burning. Make sure the area around each hot plate is clear of combustible materials and flammable liquids/vapors.

BASIC OUTLINE OF ACTIVITY

Use this space to make notes to prepare for your lesson

1. Introduction
    a. Questions
    b. Demonstration: Boiling Eggs
    c. Driving Question and discussion
2. Dissolving different substances in water
    a. Solubility predictions
    b. Hands-on activity: dissolving substances in water and discussion
    c. Dissolving simulation and discussion
    d. Hands-on activity: testing more substances for solubility
3. What happens in the process of dissolving
    a. Simulation: dissolving different substances in water
    b. Simulation questions and discussion
4. How does the polarity of solute and solvent affect solubility?
    a. Prediction question
    b. Hands-on activity: dissolving polar and nonpolar substances in water
    c. Hands-on questions and discussion
5. How do forces between molecules affect solubility?
    a. Simulation: Polarity of solvent and solute
    b. Simulation questions and discussion
6. How do forces between molecules affect boiling points?
    a. Simulation: boiling points of polar and nonpolar substances
    b. Simulation questions and discussion
7. How does changing polarity affect solubility
    a. Simulation: changing polarity
    b. Simulation questions and discussion
8. Mixing Oil and Water
    a. Simulation: Mixing Oil and Water
    b. Questions: model dissolving oil in water and discussion
    c. Demonstration: Mixing polar and nonpolar substances
    d. Revise model question
    e. Conclusion

Activity 1.1: Why don't oil and water mix?

Introducing the Lesson

Introduce the driving question for the unit "Why is a body temperature of 107°F deadly?"

Possible questions:

- *Normally our bodies keep a constant temp. Why might our bodies get a fever when we get sick?*
- *If the fever gets too high it can cause major problems even death (over 107°F).*

We will be exploring both the role of water and its interactions with other molecules in our body and the role of temperature in affecting those interactions to help answer our driving question.

Demonstration: Boiling Eggs

Prepare two beakers: one with room temperature water and one with very hot, but not boiling water (at least 165°C). The hot water should look similar to the room temperature water, no boiling should be visible. Crack one egg into each beaker and let students observe what happens.

Possible questions:

- *Why does the egg change in one beaker but not another?*
- *Eggs are made from proteins, which are a type of molecule that can be found in all living things. In the search for life on other planets, one of the main limiting factors is the temperature range on a planet's surface. Why might temperature matter?*
- *Another factor is the presence of water. Does anyone know why water would be important for life?*

Discussion: Linking back to Unit 3

Make a brief opening statement that what they observed in the egg demo and the answer to the driving question can be understood by using what they have learned in the previous unit in which students explored the interactions between molecules and the energy involved in those interactions. Use the following questions to review some key concepts.

Possible questions:

- *Why do atoms and molecules tend to stick to each other?*
- *What kinds of properties of substances have we looked at that have to do with interactions between molecules? (Think about our demos, experiments, and simulations.)*
- *How does energy change when molecules interact? (Think about previous unit and hurricanes.)*
- *How does temperature affect how molecules interact with each other?*

If these issues don't come up try to steer students toward these points:

1. Molecules interact with each other based on their structure and the magnitude electrostatic forces between them:
    a. Nonpolar substances interact with other nonpolar substances via similarly weak induced dipole interactions
    b. Polar substances interact with other polar substances via similarly strong dipole dipole interactions
2. This results in phenomena that we have observed like
    a. Energy for hurricanes
    b. Different boiling points for substance
    c. Different viscosities for substances
    d. Different interactions with stream of liquid and charged rod
3. Temperature affects these interactions
    a. Warmer temperatures evaporates more water for stronger hurricanes
    b. Solids melt and liquids boil

Tell students that these concepts will now be applied to a biological context and will focus on mixtures of substances, typically something mixed with water, because just about all things biological happen in a water environment.

Page title:

Introduction

In the previous unit, you learned how interactions between molecules of pure substances help explain various phenomena such as evaporation rate, boiling point, viscosity, etc. In this activity, you will investigate how these interactions and associated energy changes affect processes in biological systems. We will first start by exploring simple mixtures that include water.

Page title:

Dissolving a solid in water at different temperatures

In this experiment, you will investigate how sugar dissolves in water at different temperatures. Make a prediction about what will happen before doing the lab.

1. [prediction question] [drawing prompt] Recall what happened when you dropped liquid food coloring in water at different temperatures in Unit 2. Draw a model at the molecular level to show what you think will happen to solid sugar candy when you dissolve it in cold, room temperature and warm water.
[text prompt] Explain your prediction.

Student responses: Since this is an initial ideas question, student models and explanations might not be detailed. Here are some possible ideas they might include.

- Model shows water molecules bump into sugar candy molecules causing them to spread. The warmer the water, the faster the molecules move causing larger number and harder collisions with sugar candy molecules. The explanation/model shows that more frequent and more intense collisions in warmer water will cause sugar candy to dissolve faster and better in warmer water.

Lab Instructions: Dissolving candy in water at different temperatures.

Discussion:
Ask students to share their results for the hands-on activity. Encourage them to think about possible explanations for their observations.

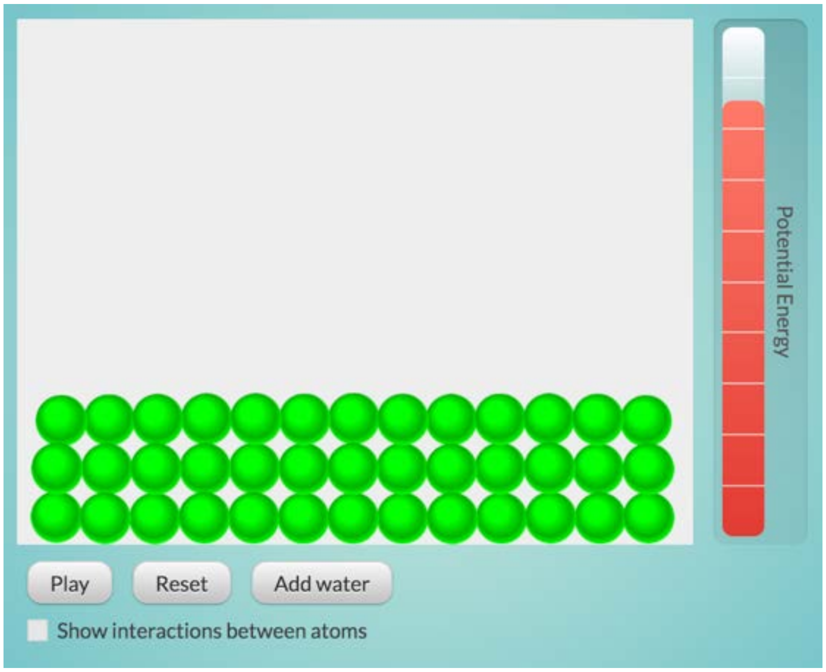
Possible questions:

- *Recall diffusion of food coloring in water of different temperatures in Unit 2. How is the sugar candy experiment similar/different from food coloring lab?*
- *How do you think water molecules cause sugar candy dissolve in water?*
- *How are interactions of sugar molecules with water molecules different at different temperatures? How are they similar?*

Page title:

What happens in the process of dissolving?

Explore the simulation to learn about the mechanism involved in the process of dissolving substances at the molecular level.



https://lab.concord.org/interactives.html#interactives/interactions/dissolving-solubility.json

2. Describe how the pattern of interactions between the various molecules changes as a substance is dissolved by another.

Student responses: At first the molecules of the solid are just interacting with each other, but when water is introduced, there are interactions between both, and the water molecules start pulling on the molecules of the solid causing them to mix with the water.

3. Describe how the potential energy changes during the process of dissolving.

Student responses: As the solid dissolves into or mixes with the water the potential energy of the system decreases.

4. [Drawing prompt] Draw a model that shows what's happening to the piece of candy as it dissolves. Show 3 steps: before, during and after all dissolved.
[text prompt] Explain your model.

Student responses:
Before: The model shows molecules of the sugar candy clumped together held by intermolecular interactions.
During: The model shows intermolecular interactions between molecules of sugar candy break and new interactions between water molecules and molecules of sugar candy form causing molecules to separate.
After: Water molecules surround molecules of the sugar candy being dissolved

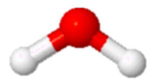
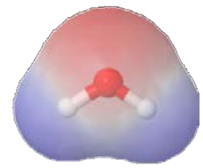
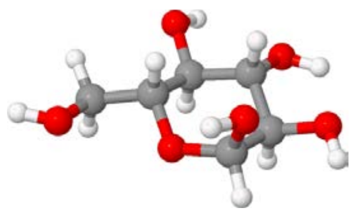
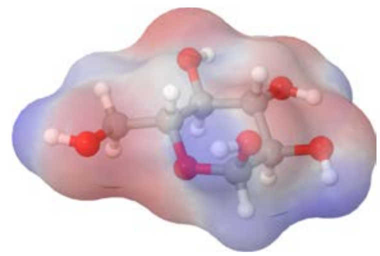
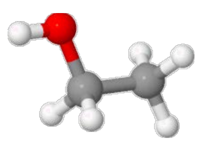
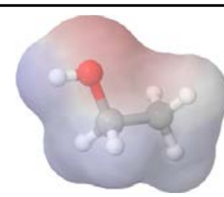
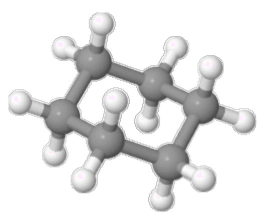
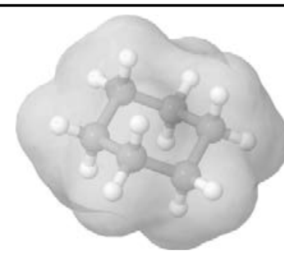
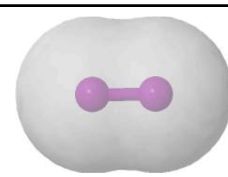
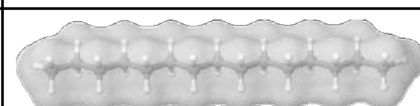
Discussion:
Use the teacher report to share their models describing what happens to the sugar candy when it dissolves in water.

Possible questions:

- *What happens to the molecules of sugar candy to cause them dissolve in water?*
- *How is energy involved in the process of dissolving sugar candy in water?*
- *How do intermolecular forces between molecules of sugar candy and molecules of water change as the candy is dissolved?*
- *Why did you see the sugar candy dissolve faster in hot water?*

Page title:

How does the polarity of substances affect solubility?

Molecule	Ball and Stick View	Surface Charge view
Water		
Sugar (glucose)		
Ethanol		
Hexane		
Iodine		
Oil		

5. [prediction question] Which of these substances do you think will dissolve in water? [select one or more substances]

- **Hexane**
- **Sugar**
- **Iodine**
- **Oil**
- **Ethanol**

Student responses: sugar, ethanol
Note: prediction questions are not to be marked correct or incorrect, but rather give students time to think before moving on.

6. Explain why you think those substances will dissolve in water.

Student responses: These molecules contain partial changes as shown in electrostatic surface maps and therefore can interact with partial charges on water molecules to form intermolecular forces and dissolve.

7. [prediction question] Which of these substances do you think will dissolve in hexane? [select one or more substances]

- **Water**
- **Sugar**
- **Iodine**
- **Oil**
- **Ethanol**

Student responses: oil, iodine

8. Explain why you think those substances will dissolve in hexane.

Student responses: these molecules contain uniformly distributed changes as shown in electrostatic surface maps and therefore can form intermolecular forces with hexane via temporary electron cloud fluctuations that result in temporary partial charges, which is the type of interaction hexane can form since it is nonpolar like these substances.

Page title:

Testing the solubility of different substances

You will now test these substances and see if they dissolve in polar water and non-polar hexane. Here is the link to the lab instructions: [Dissolving different substances in polar and nonpolar solvents].

Once you have completed the activity, discuss your observations as a class and record the consensus observations in the table below.

Discussion:
Ask students to share their observations from the experiment and record them in the table on the board.
Possible questions:

- *What patterns did you see related to which substances would mix/ dissolve together?*
- *What patterns did you see in the structures of molecules that dissolve and don't dissolve?*
- *What did you notice about how the following combinations of substances interact:*
  - *Nonpolar with nonpolar*
  - *Polar with polar*
  - *Polar with nonpolar*
- *Does anyone have other ideas/observations they want to share?*

9. Copy the class consensus observations into the table at the right, and take a snapshot of your table.

	With Water	**With Hexane**
Hexane		
Water		
Sugar		
Iodine		
Oil		
Ethanol		

https://interactions-resources.concord.org/unit4/tables/saving-html-state/obsv-water-hexane-2.html

10. What kinds of substances tend to dissolve in water? Support your answer with evidence from the experiment you just conducted.

Student responses:

- Sugar, water and ethanol contain atoms that have different electronegativity values bonded together (oxygen bonded to carbon and/or hydrogen)and they dissolved in water. Therefore, substances containing bonds between atoms with different electronegativity values substances tend to dissolve in water.
- Substances containing oxygen tend to dissolve in water. Substances that don't contain oxygen tend to not dissolve in water.

11. Based on your results, what kinds of substances will dissolve in a nonpolar substance (like hexane). Support your answer with observations from the lab.

Student responses:

- Nonpolar substances like oil and iodine will tend to dissolve in hexane because they are nonpolar and hexane is also nonpolar. Oil and iodine mostly contain bonds between atoms with similar electronegativity values, and they dissolved in hexane . Therefore, substances formed by atoms with similar electronegativity values tend to dissolve in hexane .

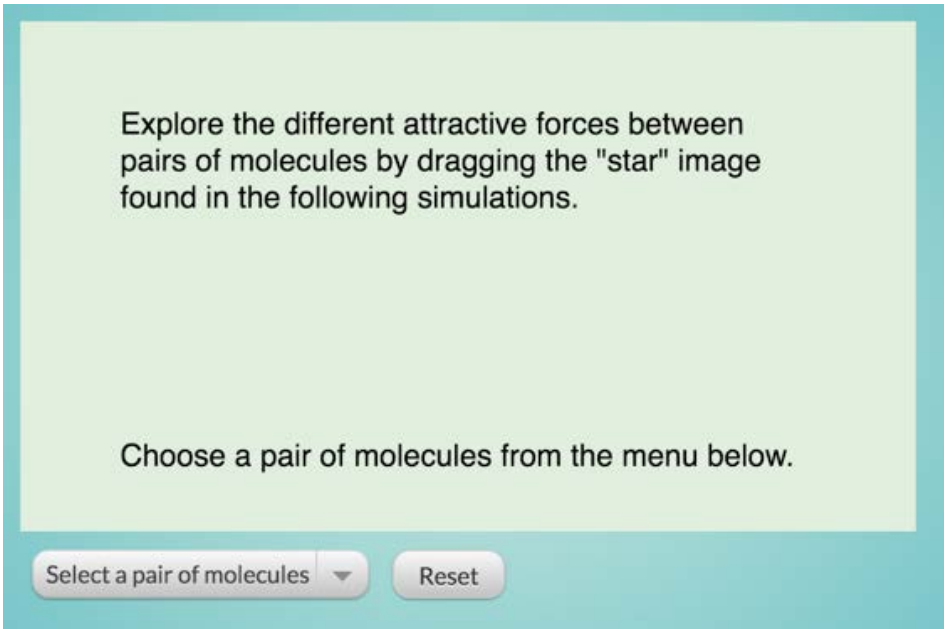
Discussion:
Ask students to share the results of their hands-on activity and review students' predictions of patterns.
Possible questions:

- *What patterns did you notice related to dissolving different solutes in water?*
- *Why do you think these patterns exist?*

Page title:

How do forces between molecules affect solubility?

Revisit the simulation from Unit 3 focusing on comparing interactions between polar and nonpolar substances. Think about what types of forces are responsible for interactions between polar and nonpolar molecules and how these forces affect solubility.



https://lab.concord.org/interactives.html#interactives/interactions/comparing-attractive-forces.json

12. Draw a model to show how polar substances and water interact at the molecular level to explain your observations.

Student responses: • Model shows polar substance with partially positive regions forming intermolecular interaction with partially negative regions around oxygen of the water molecules and partially negative regions of the polar molecule forming intermolecular interactions with partially positive regions around hydrogens of water molecules.

13. Draw a model to show how nonpolar substances and water interact to explain your observations.

Student responses:

- Model shows water's permanent partial charges forming intermolecular forces with temporary partial charges on nonpolar molecules. As a result of the constant fluctuation of the electron cloud around atoms with nonpolar bonds partial charges form on nonpolar molecules, and intermolecular forces between water and nonpolar substances can break and re-form.

Discussion:
Ask students to share their explanations for solubility patterns of polar and nonpolar substances in water. Encourage them to link their explanations back to Units 1 and 3 discussion of electronegativity, polarity, energy considerations and apply a model of temporary dipoles to help explain solubility patterns.

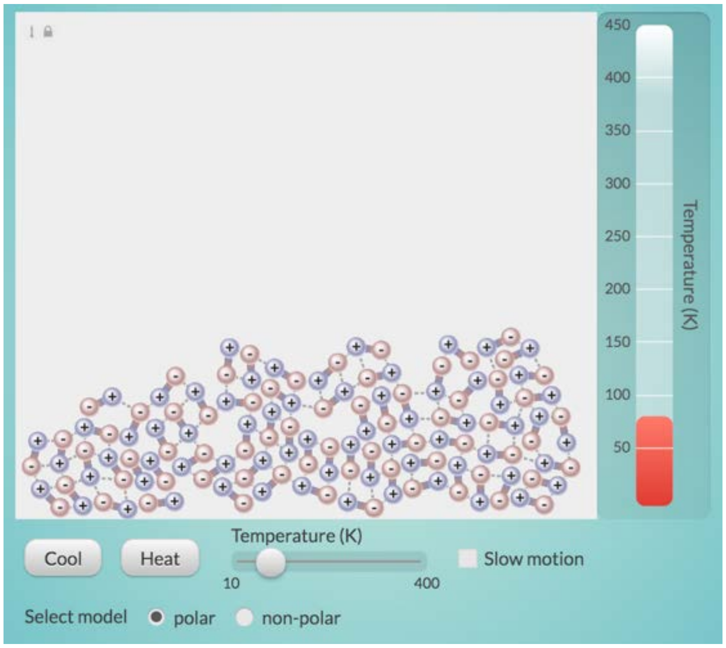
Possible questions:

- *How is electron distribution in polar and nonpolar molecules different?*
- *What forces hold polar molecules in liquid state?*
- *What forces hold nonpolar molecules in liquid state?*
- *How are intermolecular interactions involved in causing these solubility patterns?*
- *How is energy involved in causing these solubility patterns?*
- *Why might polarity affect the ability of solutes to mix with water?*

Page title:

How do forces between molecules affect boiling points?

Explore how forces between polar and nonpolar molecules affect boiling points.



https://lab.concord.org/interactives.html#interactives/interactions/boiling-point-polar-nonpolar.json

14. Construct a scientific explanation to explain why polar and nonpolar substances have different boiling points.

Student responses:

Claim: Polar substances boil at higher temperatures than nonpolar substances due to differences in attractive forces.

Evidence: From the simulations, it takes more energy (higher temperature) to boil polar substances.

Reasoning: Polar molecules interact via stable partial charges resulting from unequal electron distribution within polar molecules. These interactions hold polar molecules forming a liquid and take more energy to overcome. Nonpolar molecules don't have stable partial charges, and as a result they don't stick together as strongly as polar molecules. Therefore, it takes less energy (lower temperature) to separate them resulting in lower boiling point.

Discussion:

Ask students to share their explanations for observed boiling point differences between polar and nonpolar substances . Encourage them to link their explanations back to the Units 1 and 3 discussions of electronegativity, polarity, energy considerations and apply a model of induced temporary dipoles to help explain boiling points.

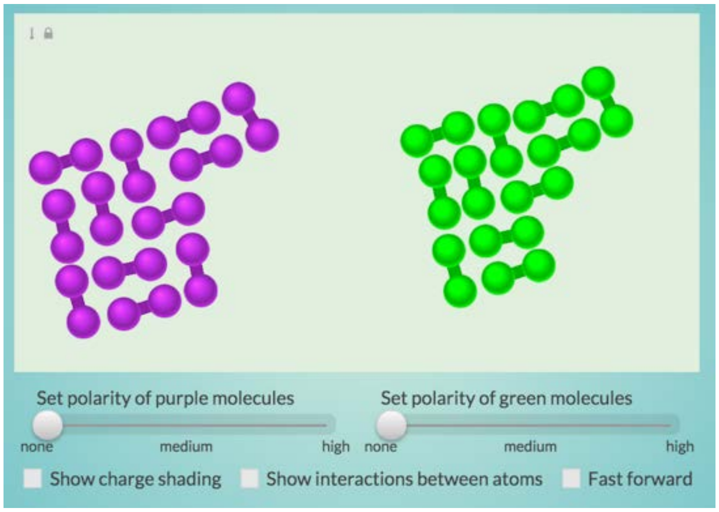
Possible questions:

- *How are forces between polar and nonpolar molecules different?*
- *How do these forces influence boiling point?*
- *What differences in boiling points did you observe for polar and nonpolar substances?*

Page title:

How does changing polarity affect solubility?

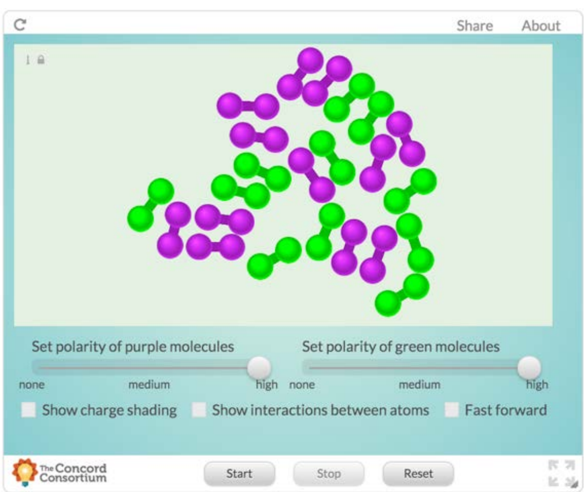
The simulation below focuses on changing the polarity of two different substances to show how polarity affects solubility. Explore the simulation. Think about what causes one substance to dissolve in another.



https://lab.concord.org/interactives.html#interactives/interactions/dissolving-experimental.json

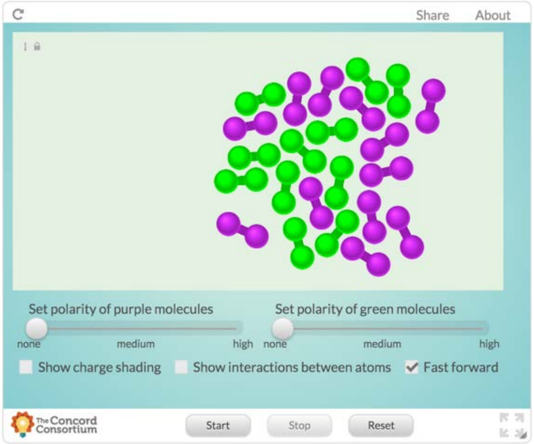
15. [Snapshot question] Take a snapshot of a situation where interactions between molecules are strong. Indicate examples of strong forces in your snapshot.

Student responses: in the example below molecules with similar polarity (high polarity) interact with each other. Strong interactions should be shown between green and purple molecules.



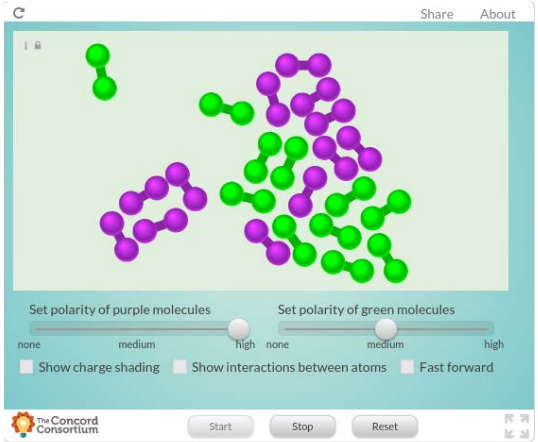
16. [Snapshot question] Take a snapshot of a situation where interactions between molecules are weak. Indicate examples of weak forces in your snapshot.

Student responses: in the example below molecules with different polarity (high and none) don't interact with each other. Weak interactions should be shown between green and purple molecules.



17. [Snapshot question] Take a snapshot of a situation where interactions between some molecules are strong and some are weak. Indicate examples of strong and weak forces in your snapshot.

Student responses: in the example below molecules with slightly different polarity. In this case molecules of the same polarity interact with each other more than with molecules with different polarity. Strong interactions should be shown between purple molecules, weak interactions should be shown between green and purple molecules.



18. Write a scientific explanation that provides a general rule (a claim) about what kinds of substances will dissolve together. Be sure to include evidence from the simulation and the lab in which different substances were mixed to observe dissolving patterns, and reasoning about molecular interactions.

Student responses:

Claim: Polar substances dissolve in other polar substances while nonpolar substances dissolve in other nonpolar substances.

Evidence: In the simulation when both substances are set to a similar polarity and mixed together, they stay mixed. However, when one substance in very polar and the other is very non-polar they separate from each other after being mixed. In the lab we saw a similar pattern of substances with similar polarities dissolving together and those with different polarity separating.

Reasoning: Polar molecules interact via partial charges resulting from unequal electron distribution within polar molecules. Nonpolar molecules also interactive between partial charges, but these partial charges are only temporary and unstable, so the attractions that can form with nonpolar molecules is typically weaker than those that can form with polar molecules. So, molecules that attract strongly to each other will be more likely to attract to each other than to molecules with which they can only form a weak attraction. Because of this, molecules with different attractions for each other will separate and not dissolve together.

Discussion:

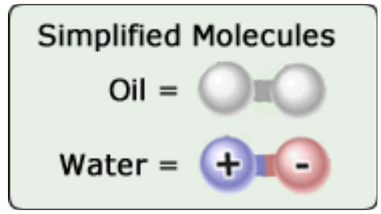
Review student models. Discuss differences between the three types of interactions including why they form and why their magnitude is different.

Possible questions:

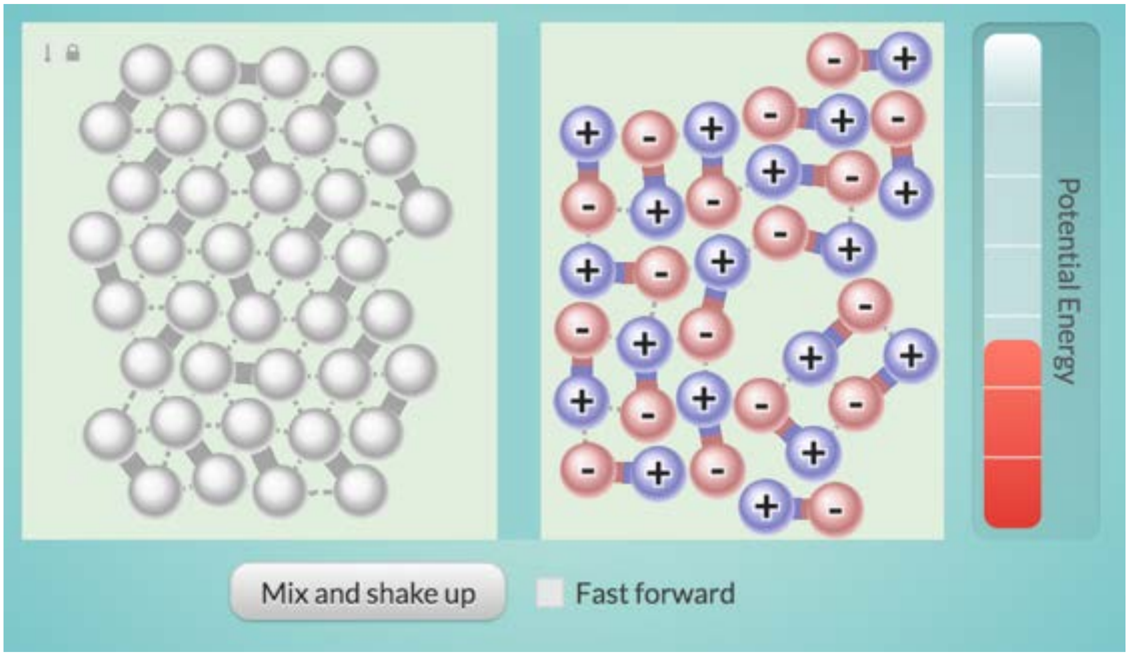
- *How does your model explain each of the three types of interactions?*
- *What is the strongest type of interactions? Why?*
- *What is the weakest type of interactions? Why?*
- *How do nonpolar molecules interact with each other?*

Page title:

Mixing oil and water



Explore the simulation showing a simplified view of non-polar oil mixing with polar water. Think about what kinds of interactions are responsible for the observed behavior of molecules.



https://lab.concord.org/interactives.html#interactives/interactions/oil-and-water.json

19. [Drawing prompt] Construct a series of bar graphs to explain energy change during the process of mixing as shown in the simulation.
[text prompt] Explain your graph in words using the space provided below.

Student responses: The bar graphs should indicate high energy of the system when oil molecules are surrounded by water molecules and significantly smaller bar graph corresponding to separate oil and water phases in the mixture.

20. Predict if the separation you observed in the simulation will occur with other combinations of polar/nonpolar liquids. Justify your prediction.

Student responses:

- Yes, any nonpolar/polar combination of liquids will separate spontaneously because the energy of the system is minimized when these types of molecules are separated.
- No, only water and oil separate spontaneously

Discussion:
Review student predictions. Ask them to support their predictions with evidence they have seen so far and reasoning based on what they have learned so far.
Possible questions:

- *Why do you think polar and nonpolar liquids are going to separate spontaneously?*
- *How does the tendency of energy to change in a certain way guide us to make certain predictions?*
- *Does anyone have a different opinion?*
- *Does everyone agree?*
- *Who thinks differently?*

Demonstration
Take the bottle of colored water and oil and mix it up. Then let it settle. Pass it around to students in the class to observe during the following discussion.
Possible questions:

- *What did you observe in the demonstration?*
- *Why did separation of the two liquids occur?*
- *Are there any interactions between the molecules of the two liquids?*
- *What kinds of interactions happen between the two liquids*

21.[drawing prompt] Revise your molecular level model of interactions between molecules right after oil and water are shaken and 2 minutes later.
[text prompt] Explain your model in words.

Student responses:

- Right after water and oil are shaken: oil molecules are located between water molecules. The permanent charges on polar molecules of water produce induced temporary charge on the nonpolar molecules of oil forming a temporary interaction. After 2 minutes: polar water molecules form intermolecular interactions with other water molecules via permanent partial charges and oil molecules form interactions with other oil molecules via induced temporary partial charges. Explanation of the model includes ideas related to how stronger interactions between polar molecules due to stronger attractive force generated by permanent partial charges cause water molecules to interact with each other therefore breaking interactions with oil molecules. Oil molecules then interact via weaker induced partial charged with other oil molecules.

Conclusion:
Ask students to share their revised models. Discuss the models and review the ideas discussed in this investigation so far including polar/nonpolar interactions, energy change associated with these interactions.
Possible questions:

- *What happens right after oil and water are mixed?*
- *What types of interactions are involved in the process of water and oil mixing?*
- *How does energy change during the process of mixing water and oil?*
- *What happens to the molecules of water and oil after two minutes?*
- *What types of interactions are present in the mixture after two minutes*

Homework:
Reading for Activity 1.1: Why does salad dressing separate in the fridge?

Activity 1.2: Can a substance dissolve in both a nonpolar and a polar liquid?

SUMMARY

Students will explore molecules that have both polar and nonpolar regions and develop a model to explain and predict the structures into which such molecules can self-assemble. Students will apply ideas related to polar and nonpolar interactions to explain interactions between mixtures of various solvents and molecules that have both polar and nonpolar regions.

LEARNING GOALS

Students will use a model to predict how molecules that are both polar and nonpolar will interact with a mixture of polar and nonpolar substances.

Disciplinary core idea	Crosscutting concept	Science and engineering practice
Relationship Between Energy and Forces: When two objects interacting through a field change relative position, the energy stored in the field is changed. (NGSS Lead States, p. 99)	*Energy and Matter:* Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system. (NGSS Appendix G, p. 86)	*Developing and using models:* • Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system. • Develop and/or use multiple types of models to provide mechanistic accounts and/or predict phenomena, and move flexibly between model types based on merits and limitations. (NGSS Appendix F, p. 53)

Students will develop a solubility model based on forces and energy, which explains how molecules that are both polar and nonpolar can self assemble into organized structures resulting in emulsifying food, cleaning oily dirt, and forming cell-membranes.

Disciplinary core idea	Crosscutting concept	Science and engineering practice

Relationship Between Energy and Forces: When two objects interacting through a field change relative position, the energy stored in the field is changed. (NGSS Lead States, p. 99)	*Patterns:* Students observe patterns in systems at different scales and cite patterns as empirical evidence for causality in supporting their explanations of phenomena. They recognize that classifications or explanations used at one scale may not be useful or may need revision using a different scale, thus requiring improved investigations and experiments. (NGSS Appendix G, p. 82)	*Developing and using models:* • Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system. • Develop and/or use multiple types of models to provide mechanistic accounts and/or predict phenomena, and move flexibly between model types based on merits and limitations. (NGSS Appendix F, p. 53)

PREPARATION

Class Time: 120 min.

Materials (for the whole-class demonstration)

- Dish soap
- Cooking oil
- Two 250 ml beakers
- Labels

HOMEWORK

Reading for Activity 1.2 "Can Water and Oil Ever Form a Stable Mixture"?

BASIC OUTLINE OF ACTIVITY

Use this space to make notes to prepare for your lesson

1. Introduction
   a. Discussion
   b. Demonstration: mystery substance
   c. Prediction question
   d. Simulation: Amphipathic molecules
   e. Simulation questions
   f. Simulation discussion
2. How does molecular structure affect mixing?
   a. Simulation: Surface charge
   b. Simulation questions
   c. Simulation discussion
3. How does soap get rid of oil stains?
   a. Simulation: soap and oil
   b. Simulation questions
   c. Simulation discussion
   d. Questions
   e. Simulation: soap in polar and nonpolar solvents
   f. Questions
   g. Discussion and Conclusion

Activity 1.2: Can a substance dissolve in both a nonpolar and polar liquid?

Introduction:
Review ideas related to mixing of polar and nonpolar substances discussed in the previous activity. Encourage students to think about what parts of molecules are responsible for observed interactions and why.

Possible questions:
- *What kinds of substances tend to mix/not mix together? Why?*
- *What is it about the structure of the molecules that causes them to mix or separate if forced to mix by shaking? Why?*

Page title:

Introduction

In the last activity, you collected evidence that substances with similar strengths of attractive forces dissolve together (i.e. polar with polar and nonpolar with nonpolar). Observe the teacher demo and make predictions about the mystery substance used in the demo.

Demonstration:
Prepare two beakers labeled "water" and "oil". Prepare a container labeled "mystery substance" containing dish soap. Add a little bit of dish soap (approximately 1 tablespoon) to the water and about a tablespoon of dish soap to the oil, and use a string rod to stir the "mystery substance". Allow students to observe what happens. Discuss their observations.

Possible questions:

- *What do you notice?*
- *What characteristics of the mystery substances might account for your observations?*

1. [prediction question] What do you think would happen if the mystery substance was put into a container with water and oil (naturally separated from each other)?

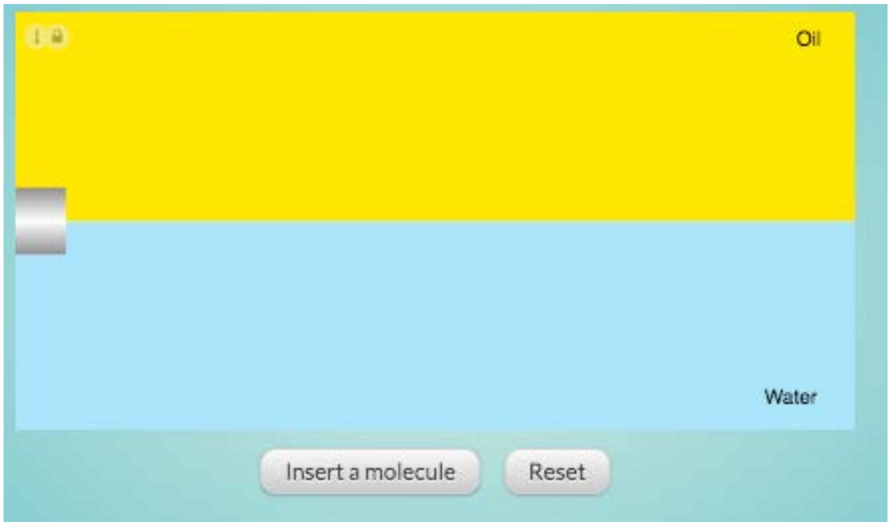
Student responses: Since this is an initial idea, student explanations might not be detailed. The mystery substance didn't show any phase separation when dissolved in both water and oil. This implies that the substance has molecules that have polar and nonpolar regions. Alternatively, mystery substance could have both polar and nonpolar molecules. Examples of possible descriptions of what might happen when the mystery substance is put into a container of water and oil might include:

- The mystery substance composed of molecules with polar and nonpolar regions. When placed in a container with naturally separated water and oil, molecules of the mystery would stay near the interface with polar regions in water phase and nonpolar regions in oil phase.
- The mystery substance is composed of polar and nonpolar molecules. When placed in a container with naturally separated water and oil, polar molecules of mystery substance go into water phase and nonpolar molecules go into the oil phase.

Page title:

Sorting molecules

Explore the simulation. Think about what kind of molecular structure would result in the observed behavior of the different types of molecules in the simulation.



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2. [drawing prompt] Draw a model to explain the behavior of each of the three types of substances you observed in the simulation. Be sure to include detail at the molecular level. [text prompt]Explain your model.

Student responses: Model shows three types of molecules. Polar molecules are shown to have nonuniform charge distribution between atoms, and they go into the water. Nonpolar molecules with uniform charge distribution between atoms, and they go into oil. Amphipathic molecules have regions with both nonuniform charge distribution and uniform charge distribution. These molecules stay at the interface. Note: students are not supposed to know the term "amphipathic."

Discussion:
Ask students to share their models of the three substances from the simulation. Encourage students to think about possible molecular structures for the mystery substance (grey particles form the simulation), which could be responsible for why the molecules stay at the interface between water and oil

Possible questions:

- *What characteristics do molecules that go into the water layer have?*
- *What characteristics do molecules that go into the oil layer have?*
- *What characteristics do molecules that stay between the water and oil layers have?*

Make links back to the previous unit where students reviewed structures of molecules and made estimates of polarity using oxygen as indicator of uneven sharing of electrons in molecules.

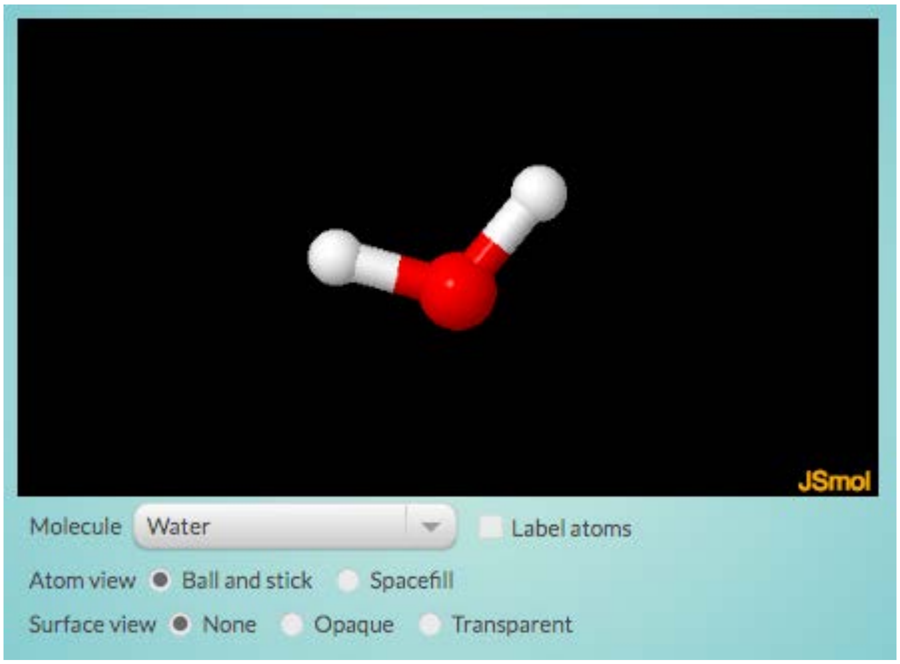
Possible questions:

- *How are atoms and how they are bonded in the molecules that go into the water layer different from the atoms and how they are bonded in molecules that go into the oil layer?*
- *How are atoms and how they are bonded in molecules that stay between water and oil similar/different from the atoms and bonding patterns of the other two types of molecules?*

Page Title:

How does molecular structure affect mixing?

Explore the various molecules, focusing on the types of atoms and how they are bonded together. Consider how patterns of atom type and bonding affect the properties of a molecule and the ability of a substance made of those molecules to mix with other substances.



https://lab.concord.org/interactives.html#interactives/interactions/elements-and-polarity.json

3. [text prompt] Which atoms and bonding patterns seem to cause an uneven sharing of electrons? Support your conclusion with evidence from the simulation and ideas about electronegativity discussed in the previous unit.

Student responses: Atoms of oxygen, nitrogen and phosphorus tend to cause uneven sharing of electrons when bonded to hydrogen. This is supported by the uneven electron distribution shown for water, ammonia, methylamine, propanol molecules. Uneven sharing of electrons happens because the electronegativity difference between oxygen/nitrogen/phosphorus and hydrogen is large, which causes electron density to be permanently shifted towards more electronegative oxygen/nitrogen/phosphorous atoms.

4. Which of the molecules might have been the mystery substance in the previous simulation? (Select all that apply)

- **Water**
- **Ammonia**
- **Cholesterol**
- **Methylamine**
- **Mineral oil**
- **Phospholipid**
- **Propanol**
- **Stearic acid (used in soap)**

Student responses: Soap, cholesterol, and phospholipids are likely to be the mystery substance.

5. Explain the reasoning behind your choices.

Student responses: All of these structures have highly electronegative atoms (like oxygen and phosphorus) that form unequal charge distribution regions. These regions will interact with polar solvents (like water). These structures also have long nonpolar parts formed by atoms with similar electronegativity values (carbon and hydrogen) which result in uniform charge distribution. These regions will interact with nonpolar solvents (like oil). As a result these kinds of molecules will tend to stay between the polar and nonpolar phases.

6. Explain why someone might pick propanol for the mystery substance, but how that would be incorrect.

Student responses: Propanol has both polar and nonpolar regions, but the nonpolar region is not long enough to allow propanol to interact with nonpolar molecules.

7. How might you modify the propanol molecule by adding, subtracting, or changing atoms to make it a "mystery substance" possibility?

Student responses: You could add more CH_2 groups to make a long nonpolar region that will interact with nonpolar solvents.

Discussion:

Ask students to share their thoughts as to what the structure of the mystery substance might be. Encourage them to think about what structural characteristics of the mystery substance might be responsible for the observed properties.

Possible questions:

- *Which molecules from the ones explored in the simulation are likely to be the mystery substance? Why?*
- *Why might considering propanol for mystery substance be incorrect?*
- *How would you modify a propanol molecule to make it a mystery substance? Why?*
- *What characteristics do molecules that stay between the water and oil layers have?*

At this point you can reveal that the mystery substance in this case was soap, which students will explore in greater detail in the following activity. Also, point out that in this particular case the substance happens to be soap, but there might be other substances that could exhibit similar properties. Encourage students to think about what those properties might be.

Possible questions:

- *Which molecules are also likely to act like soap?*
- *What is it about the structure of these molecules that explains the observations?*

Page title:

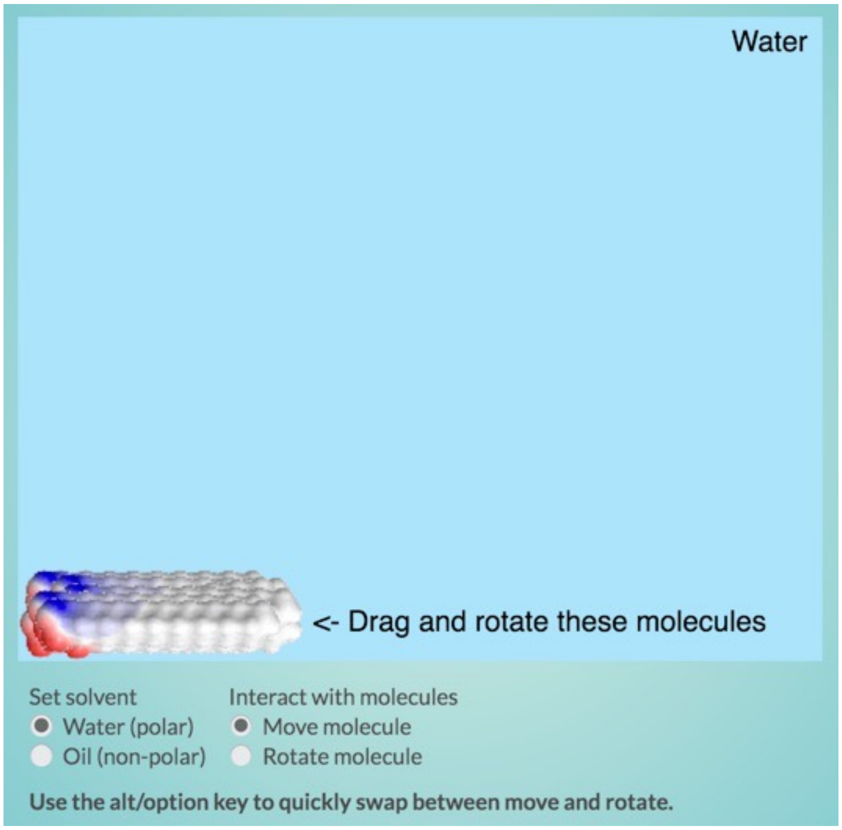
Predicting dissolving patterns for soap

Have you ever noticed how hard it is to get oil or grease off of your hands? Typically you need soap and water to get your hands clean.

8. Why do you think greasy/oily stuff won't wash off your hands just with water?

Student responses: Grease and oil are made of polar molecules that don't dissolve in water.

What if something like soap was put into pure water or pure oil? Use the snapshot questions below to show how you think soap molecules would or would not mix with the surrounding oil or water. Would they form any patterns or be randomly distributed?



https://lab.concord.org/interactives.html#interactives/interactions/drawing-micelles.json

9. [Prediction question] [Drawing prompt] Set the model to have a water environment (if not already set that way), and move the soap molecules to show how they might position themselves in water. Then take a snapshot.
[text prompt] Explain why you positioned the molecules in that way.

Student responses: Students are likely to either position the molecules randomly, or notice that the polar "heads" of the molecules will dissolve in the water while the nonpolar tails will not. The point is not to get the right answer now, but to see how students are reasoning about their choices.

10. [Prediction question] [Drawing prompt] Set the model to have an oil environment, and move the soap molecules to show how they might position themselves in oil. Then take a snapshot.
[text prompt] Explain why you positioned the molecules in that way.

Student responses: Students are likely to either position the molecules randomly, or notice that the nonpolar "tails" of the molecules will dissolve in the oil while the nonpolar tails will not. The point is not to get the right answer now, but to see how students are reasoning about their choices.

Discussion:
Ask students to share their molecular diagrams and explain why they positioned the molecules in this way.

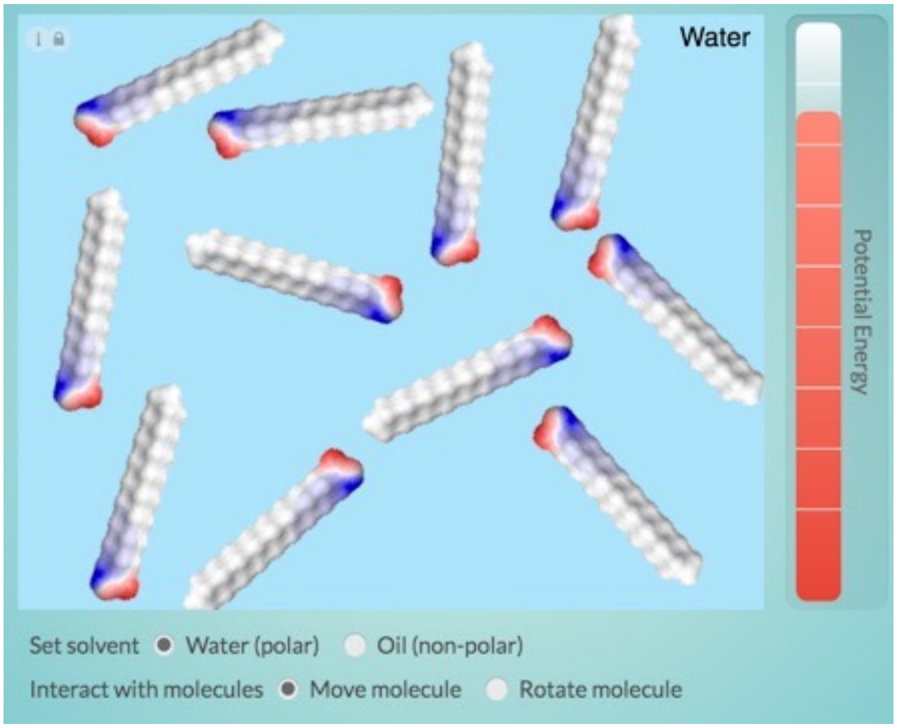
Possible questions:

- *How are these models similar or different?*
- *What do you think of that explanation? Are there parts that you would like explained more?*
- *How is this representation similar or different from what you did?*
- *What forces are at play that would cause the molecules to form that pattern?*

Page title:

Self-assembly of molecules into organized structures

Use the simulation to check your prediction for what happens to soap if put in pure water or pure oil.



https://lab.concord.org/interactives.html#interactives/interactions/micelles.json

11. How was your prediction of what would happen when soap molecules are put in water and oil similar to or different from what the model shows?

Student responses: Students are likely to either position the molecules randomly, or notice that the nonpolar "tails" of the molecules will dissolve in the oil while the nonpolar tails will not. The point is not to get the right answer now, but to see how students are reasoning about their choices.

12. Explain why different structures form in water and oil. In particular, discuss how different parts of soap molecules interact with water molecules to form different arrangements.

Student responses: In polar solvents like water, soap molecules form the structure with polar heads facing water molecules and long nonpolar tails moving away from polar water molecules.

13. [drawing prompt] Construct bar graphs that show what happens to the potential energy of a soap solution when soap is first mixed in oil and then when it forms a stable structure. Do the same for soap in water.
[text prompt] Explain your graphs, and make sure to relate energy changes with corresponding changes in position of the molecules.

Student responses: For water, the bar graph should indicate higher potential energy when nonpolar tails of soap molecule are interacting with water, and lower energy arrangement when nonpolar tails are encapsulated within micelles with polar heads sticking outward interacting with water molecules. For oil, the bar graph should indicate higher energy arrangement when polar heads of soap molecule are interacting with oil, and lower energy arrangement when nonpolar tails are sticking outwards interacting with oil and encapsulated polar "heads" within the formed sphere-like structures.

Explanation of graphs includes the following ideas:
When strongly attracting objects can get closer to each other, then potential energy is reduced. In the case of soap in water, the closer the water and polar part of the soap can be the lower the energy. So the potential energy decreases when the nonpolar parts are away from the water as much as possible. In oil the strongly attracting parts are just the polar parts of the oil molecules, so potential energy is minimized when the polar heads of the soap molecules are grouped together.

Discussion:
Ask students to share their bar graphs and explain why different structures of soap form in different solvents.

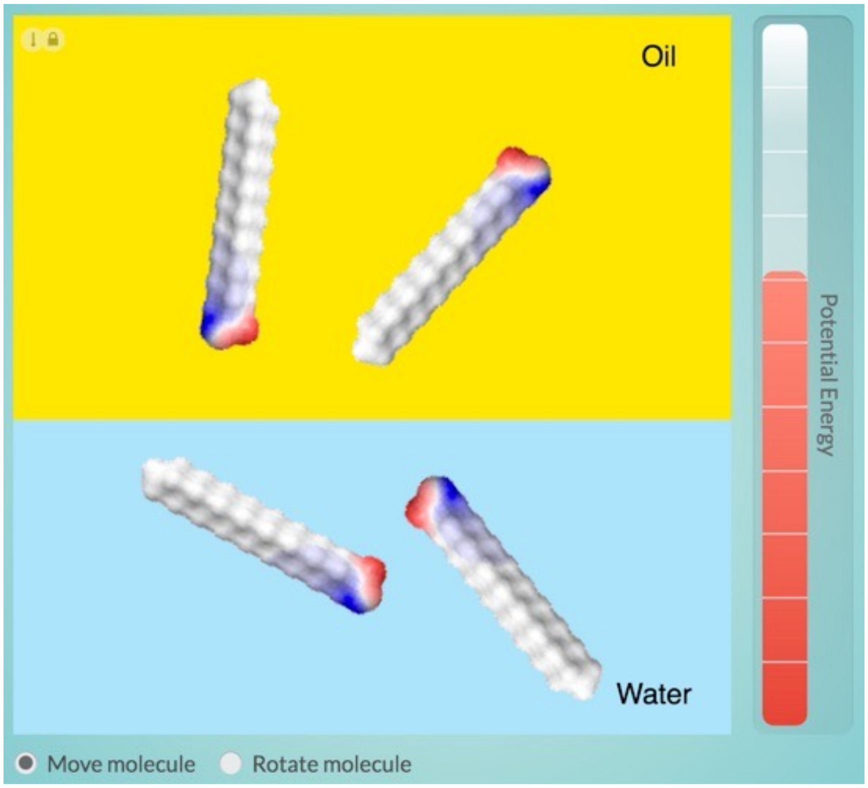
Possible questions:

- What kinds of structures do soap molecules form when placed in water?
- What kinds of structures do soap molecules form when placed in oil?
- How are the structures formed by soap molecules different when placed in water and oil? Why?
- How does energy of the system change when soap molecules are placed in water? Why?
- How does energy of the system change when soap molecules are placed in oil? Why?
- What is the difference between how energy of the system changes for water molecules placed in water vs. oil? Why?

Page title:

Soap in an oil and water mixture

Use this simulation to explore how soap molecules behave when they are allowed to diffuse in an environment where there is both oil and water.

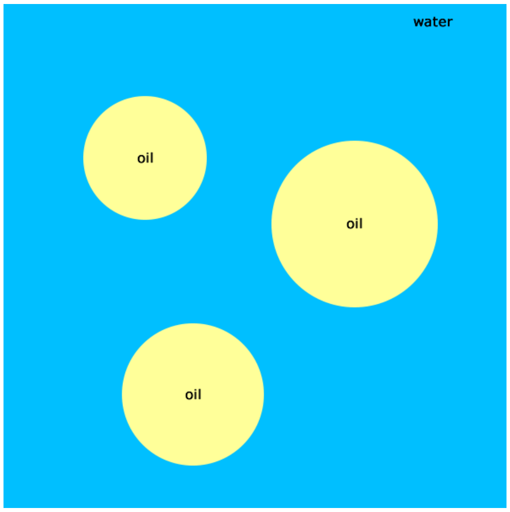


https://lab.concord.org/interactives.html#interactives/interactions/polar-and-non-polar-interface.json

14. Using what you know about how things dissolve, explain the behavior you see in the simulation. Make sure to discuss ideas of relative forces, interactions, and energy in your answer.

Student responses: The polar parts of the soap molecule will have stronger attractions to the polar water molecules, leaving the nonpolar parts of the molecule to interact with the similarly weakly interacting non-polar oil. When the polar parts are in the polar water and nonpolar parts are in the nonpolar oil potential energy goes down. Nature tends to naturally move toward lower potential energy states.

15. [Drawing prompt] **When you successfully wash greasy oily stuff off of your hands you are basically mixing up water, oil, and soap. During mixing tiny blobs of oil will mix with the water. Show where the soap molecules will be in that situation. (Make up a simple representation of a soap molecule that can quickly be drawn.)**
[text prompt] Explain why you positioned the soap molecules that way.



Student responses: The model shows nonpolar parts of soap molecules interacting with nonpolar molecules of oil and grease and polar parts of soap interactive with water. The strong attractive forces between the polar part of the soap and the polar water will cause them to mix, while the weakly attracting nonpolar part of the soap will mix with the nonpolar oil. Energy will be minimized when the soap straddles the boundary between the water and oil.

16. Without soap, the grease and oil only temporarily mix with the water, quickly separating which prevents the grease and oil from washing away.

Consider how you drew the soap molecules in the previous question, and explain how the soap molecules help keep the oil droplets mixed in with the water, so they can be washed away.

Student responses: The soap can dissolve in both water and oil, so the polar parts of the soap surround the oil droplets allowing the whole droplet to say in the water.

Discussion:
Ask students to share their models and discuss structural characteristics of soap that allow it to help you get rid of greasy stains.

Possible questions:

- How does soap help you get rid of greasy stains?
- What is it about the structure of soap molecules that helps dissolve oil molecules?
- What is it about the structure of soap molecules that helps it dissolve oil molecules while also being soluble in water?

Homework: Reading for Activity 1.2: Can Water and Oil Ever Form a Stable Mixture?

Activity 1.3: What are proteins and how do they fold into biologically important shapes?

SUMMARY

In the last activity students explored the interactions between small polar and non-polar molecules. Proteins are large molecules that have both polar and non-polar parts. They perform many different functions in our bodies, which depend on the shape of these molecules. Students will explore the structure of proteins through computer models, and through simulations explore how the final shape of a protein molecule is a combination of interactions between different parts of the molecule and with the solvent in which the protein resides (i.e. water). In earlier units energy minimization and stability were explored in the context of molecule formation. Here that concept is applied to larger systems of molecules.

LEARNING GOALS

- Students will use models of molecules to
  - determine whether parts of those molecules are polar or non-polar based on the electronegativities of the atoms in each part
  - make predictions about how an amino acid chain will fold based on the polar and non-polar parts.

Disciplinary core idea	Crosscutting concept	Science and engineering practice
Organization of Matter and Energy Flow in Organisms: The sugar molecules thus formed contain carbon, hydrogen, and oxygen; their hydrocarbon backbones are used to make amino acids and other carbon-based molecules that can be assembled into larger molecules (such as proteins or DNA) used, for example, to form new cells. (NGSS Lead States, p. 106)	*Energy and Matter:* Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system. (NGSS Appendix G, p. 86)	*Developing and using models:* • Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system. • Develop and/or use multiple types of models to provide mechanistic accounts and/or predict phenomena, and move flexibly between model types based on merits and limitations. (NGSS Appendix F, p. 53)

- Students will analyze data to track potential energy changes during intermolecular interactions to explain observed phenomena.

Disciplinary core idea	Crosscutting concept	Science and engineering practice

Relationship Between Energy and Forces: When two objects interacting through a field change relative position, the energy stored in the field is changed. (NGSS Lead States, p. 99)	*Energy and Matter:* Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system. (NGSS Appendix G, p. 86)	*Analyzing and interpreting data:* • Analyze and interpret data to provide evidence for phenomena • Evaluate impact on new data on a working explanation and/or model of a proposed process or system (NGSS Appendix F p. 57)

- Students will provide a scientific explanation linking solubility and stable structures to energy minimization.

Disciplinary core idea	**Crosscutting concept**	**Science and engineering practice**
Relationship Between Energy and Forces: When two objects interacting through a field change relative position, the energy stored in the field is changed. (NGSS Lead States, p. 99)	*Energy and matter:* Students learn that the total amount of energy and matter in closed systems is conserved. They can describe changes of energy and matter in a system in terms of energy and matter flows into, out of, and within that system. They also learn that energy cannot be created or destroyed. It only moves between one place and another place, between objects and/or fields, or between systems. Energy drives the cycling of matter within and between systems. (NGSS Appendix G, p. 86)	*Constructing explanations and designing solutions:* • Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. • Apply scientific ideas, principles, and/or evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects. • Apply scientific reasoning, theory, and/or models to link evidence to the claims to assess the extent to which the reasoning and data support the explanation or conclusion. (NGSS Appendix F p. 61)

PREPARATION

Class Time: 120 min.

HOMEWORK

Reading for Activity 1.3 "What are proteins and why are they important?"

BASIC OUTLINE OF ACTIVITY

Use this space to make notes to prepare for your lesson

1. Introduction
    a. Discussion
2. What are the building blocks of proteins?
    a. Simulation
    b. Questions
    c. Discussion
3. Why are some amino acids more polar than others?
    a. simulation
    b. Questions
4. Which parts of a protein are polar and non-polar?
    a. Simulation
    b. Questions
    c. Discussion
5. How do proteins fold into different shapes?
    a. Discussion
    b. Simulation
    c. Questions
    d. Discussion
6. What do protein folding patterns depend on?
    a. Simulation
    b. Questions
    c. Discussion
7. What do proteins look like?
    a. Simulation

b. Questions

c. Discussion

8. Conclusion

Activity 1.3: What are proteins and how do they fold into biologically important shapes?

Introduction:
Summarize the ideas students have explored so far in the investigation including interactions between polar, non-polar, and amphipathic molecules (molecules with both polar and non-polar parts). Remind them that both molecular structure and energy changes in the system determine the stability of interactions between simple molecules they have studies thus far.

In this activity students will apply similar principles to look at more complex molecules that have both polar and non-polar parts- proteins. Ask students to share their ideas about what proteins are and why are they important. It might be easier to talk about proteins if you focus on food, since this is a topic familiar to students.

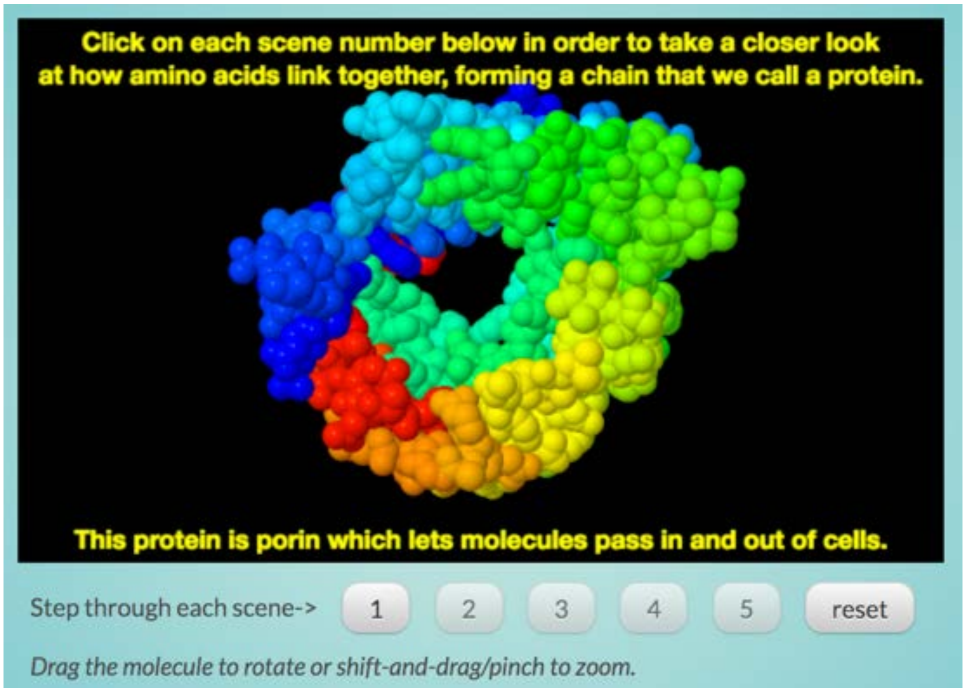
Possible questions:

- *What are proteins?*
- *Where can you find proteins?*
- *What types of food are considered good sources of protein?*
- *Why is protein important for us?*
- *Do we have proteins in our bodies?*
- *Do plants have proteins?*
- *What do proteins look like?*

Note: This is initial ideas discussion, so students might not know what proteins are at this point.

Page title:
What are the building blocks of proteins?

Proteins are important molecules that perform many functions within your body (and are part of all living things). Each protein molecule is actually made by linking together smaller molecules called amino acids. Explore the protein below which sits in cell membranes and allows other key molecules to pass into and out of cells.



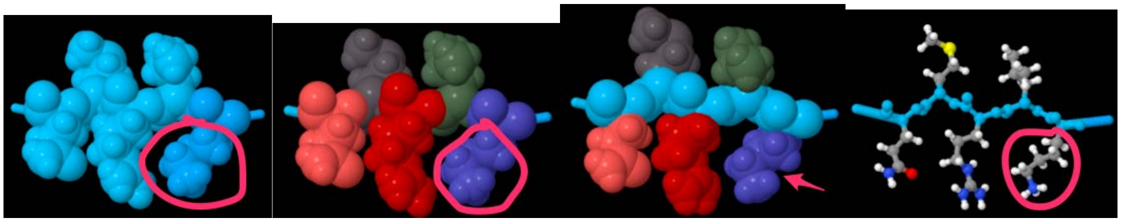
https://lab.concord.org/interactives.html#interactives/interactions/amino-introduction.json

1. What is the purpose of the backbone part of an amino acid, which is the same for every amino acid?

Student responses: That is the part that links together the amino acids.

2. [drawing prompt] Find a scene that shows the side chain part of an amino acid and take a snapshot of it. Then circle the part that is the side chain.

Student responses: Students might take any one of the following images. (Note these are examples, not all possible right answers.)



Discussion:
Ask students to share their classification of amino acids and explain why they have classified them as polar or non-polar

Possible questions:

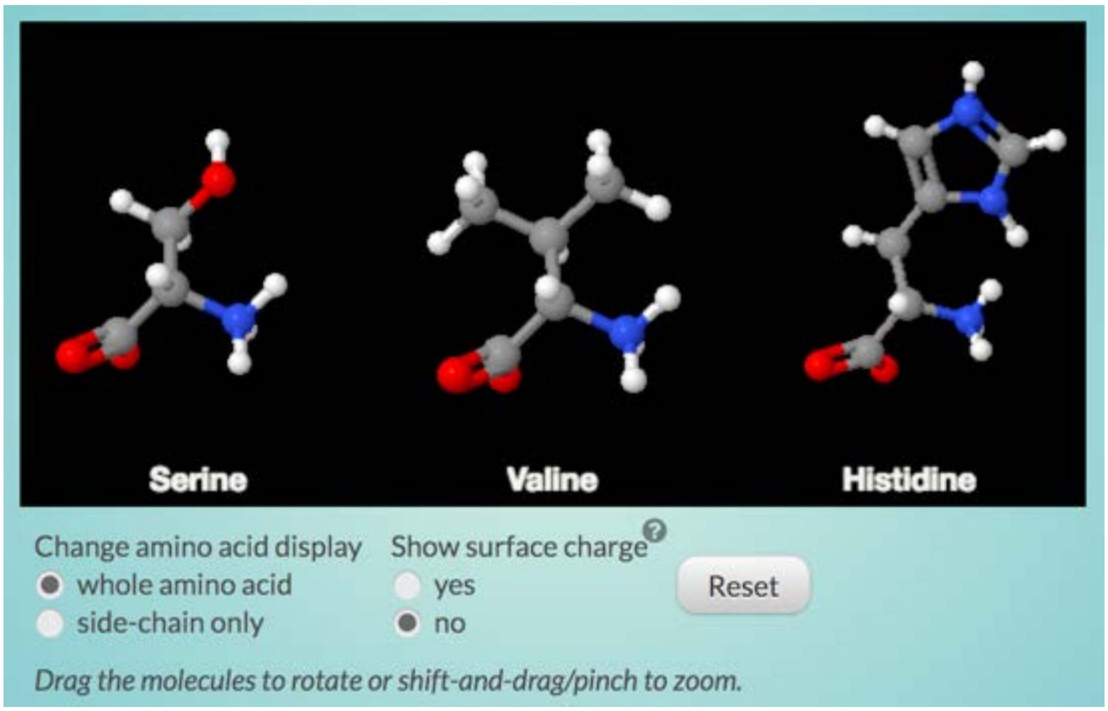
- What principles did you use to classify amino acids as polar or non-polar?
- Why did you classify… as polar?
- Why did you classify...as non-polar?

Page title:

Why are some amino acids more polar than others?

Because proteins are long flexible molecules, not only can they interact with the water they are typically surrounded by, but also one part of a protein and interact with another part. There are twenty different amino acids that can be linked together to make a protein. Each amino acid can be polar, non-polar, or have a full electric charge (positive or negative).

Below are three examples of the 20 possible amino acids. Explore their structure to understand which parts are the same and which are different. Depending on polar or non-polar properties of the amino acids a protein will fold into different structures.



https://lab.concord.org/interactives.html#interactives/interactions/amino-examples.json

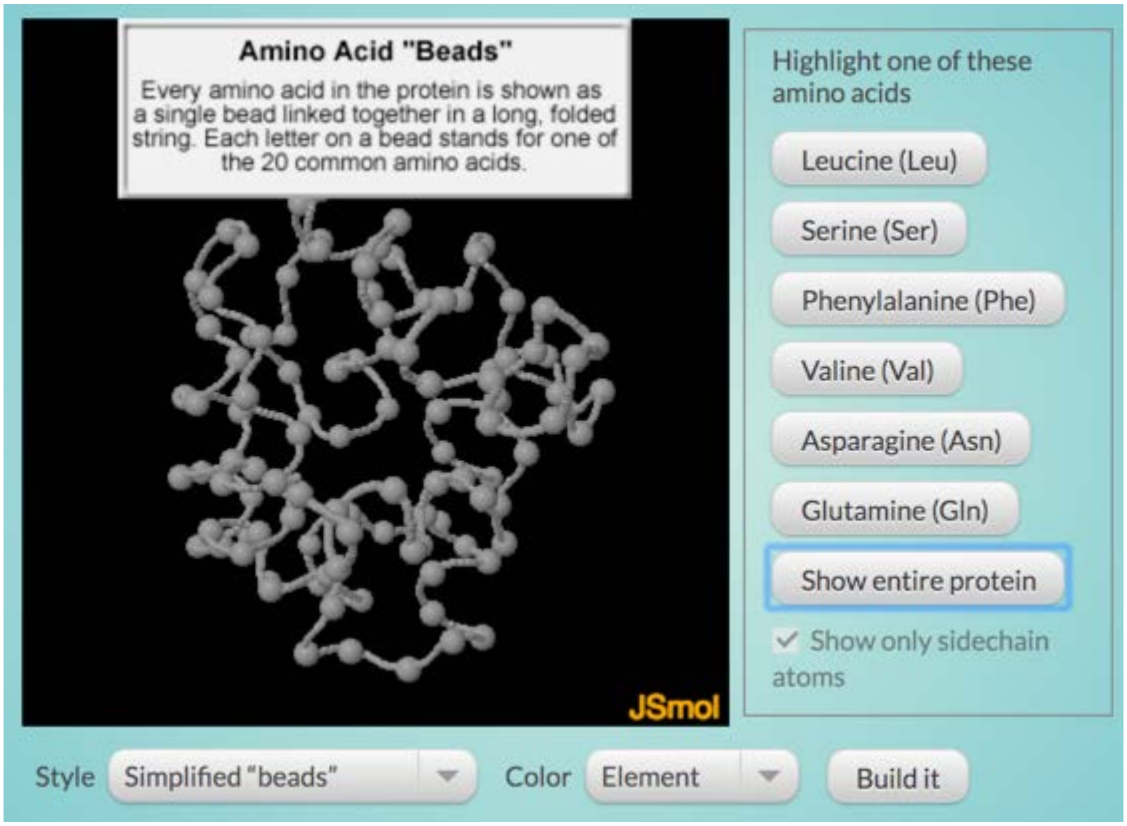
3. Explain why serine is a polar amino acid while valine is non-polar.

Student responses: The side chain of serine includes oxygen bonded to hydrogen. Oxygen has a much higher electronegativity than hydrogen, so it attracts electrons more strongly to itself causing an imbalance of charge. This makes Serine polar. The side chain of valine has carbon-carbon bonds and carbon-hydrogen bonds. All of the atoms have similar electronegativity, so electrons are evenly shared, resulting in a non-polar surface.

Page title:

Which parts of a protein are polar and non-polar?

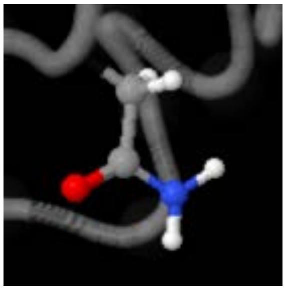
Below is a protein that has an option to show each amino acid as a single "bead". This view can help show how a protein molecule folds up into a three-dimensional shape. Use this model of a protein found in egg whites to explore some of the 20 different amino acids that can be linked together to make proteins.



https://lab.concord.org/interactives.html#interactives/interactions/exploring-protein-3d-structure.json

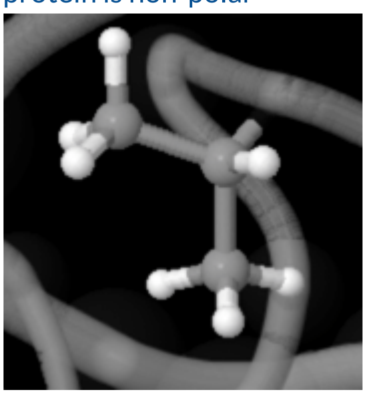
4. [drawing prompt] Take a snapshot that highlights a polar part of the protein. Label the snapshot to show why it is polar.
[text prompt] Explain why the amino acid sidechain in your snapshot is polar.

Student responses: The amino acid highlighted below is asparagine. The side chain of asparagine includes nitrogen bonded to hydrogen. Nitrogen has a much higher electronegativity than hydrogen, so it attracts electrons more strongly to itself causing an imbalance of charge. Therefore, this part of the protein is polar



5. [drawing prompt] Take a snapshot that highlights a non-polar part of the protein. Label the snapshot to show why it is non-polar.
[text prompt] Explain why the amino acid sidechain in your snapshot is non-polar.

Student responses: The amino acid highlighted below is valine. Valine sidechain consists of carbon and hydrogen, which have similar electronegativities. Therefore, this part of the protein is non-polar



Discussion:
Ask students to share their classification of amino acids and explain why they have classified them as polar or non-polar

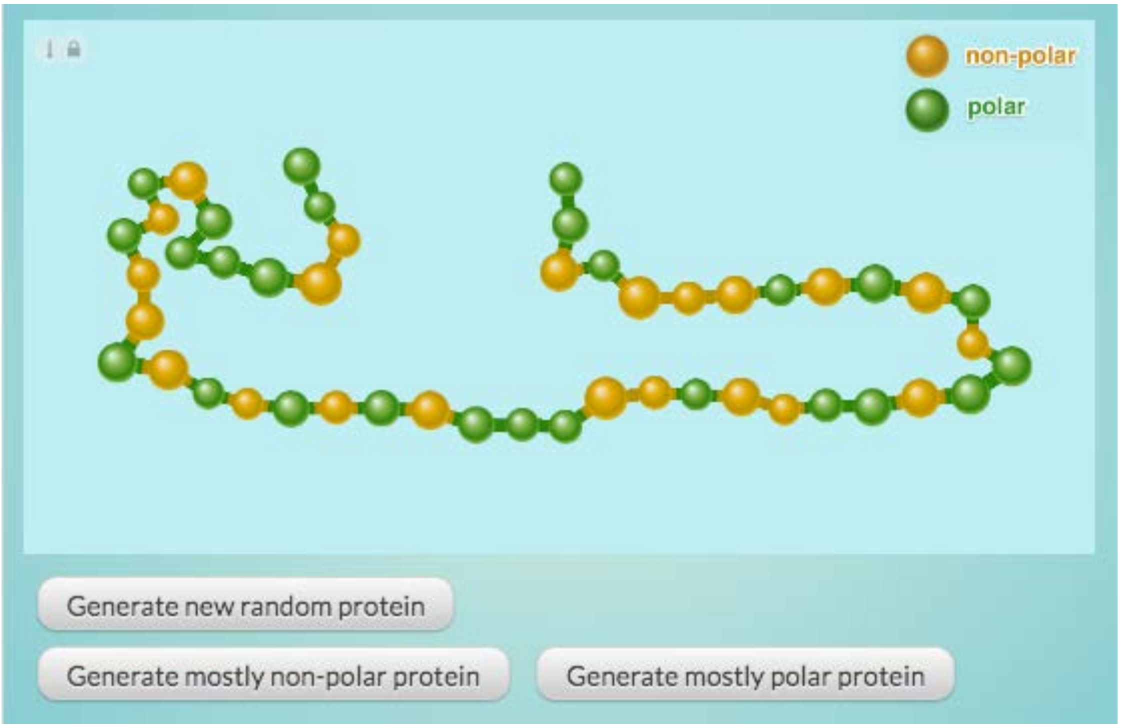
Possible questions:
- What principles did you use to classify amino acids as polar or non-polar?
- Why did you classify… as polar? Why?
- Why did you classify...as non-polar? Why?

Page title:
How do proteins fold into different shapes?

Discussion:
Recall from the previous activities how there are varying attractive forces between polar/polar, polar/non-polar, and non-polar/non-polar. Perhaps show this interactive again: http://lab.concord.org/interactives.html#interactives/sam/intermolecular-attractions/2-comparing-dipole-dipole-to-london-dispersion.json

Possible questions:
- What determines the strength of interactions between molecules?
- Describe the differences between the strengths of the forces between different kinds of molecule pairs.
- How does the property of polarity affect interactions with water molecules?
- How does the polarity of a molecule or part of a molecule affect how it dissolves in water?

Use the simulation below to explore how several different proteins fold up to form a stable structure in water. As you try different proteins, look for patterns in the structures they form and where the polar and non-polar amino acids end up as they interact with themselves and with the water molecules (not shown but present surrounding the protein).



https://lab.concord.org/interactives.html#interactives/interactions/protein-folding.json

6. What patterns can you identify in the structures that are formed? (In other words, where do the polar and non-polar amino acids end up in a water environment?)

Student responses: The polar amino acids tend to end up near the outside of a protein. If you make the protein completely out of polar amino acids, then it won't fold up.

7. Use what you know about polar and non-polar interactions to explain why these patterns of protein structure form in water.

Student responses:
All of the amino acids that make up the protein are attracted to each other and to the surrounding water molecules. However, the polar amino acids are more strongly attracted to themselves and to water, so they tend to end up on the outside of the protein. The non-polar amino acids are squeezed out from between the more strongly attracted polar amino acids and water, so the non-polar ones tend to cluster in the middle of the protein. If the protein is made from all amino acids, it doesn't fold up because of the strong interactions with the water. Basically, the fully polar protein dissolves in the polar water. If part of the protein is polar and part non-polar, the polar part will dissolve in the water while the non-polar part will not, causing the protein to fold up with the non-polar amino acids clumped together away from the water and the polar ones near the surface attracted to the water.

Discussion:
Ask students to share their ideas about what shapes the protein chains would take in water and in oil. Encourage them to explain their answers using polar and non-polar interactions discussed earlier.

Possible questions:
- What did you notice about how different parts of a protein chain interact with each other and with the surrounding water molecules?
- How would the protein structure change if it was placed in non-polar oil? Why?

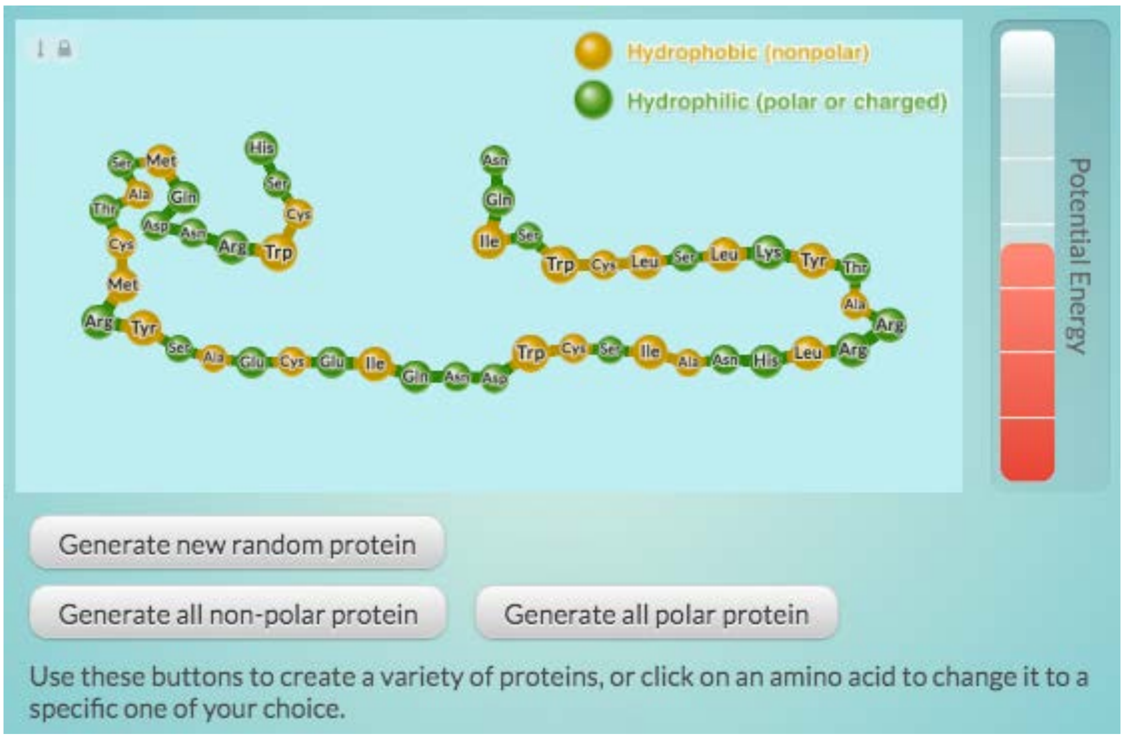
Page title:
What do protein folding patterns depend on?

Amino acids can be grouped two broad categories polar/charged and non-polar.

The polar and charged ones are called **hydrophilic**, which means "water loving."

The non-polar ones are called **hydrophobic**, which means "water fearing."

In this simulation you can create your own protein by clicking on an amino acid to change it to one you select from the list of possible amino acids. Try creating several different proteins and observe where the different types of amino acids end up when the protein folds up in a water environment.



https://lab.concord.org/interactives.html#interactives/interactions/protein-folding-exploring.json

8. How does the strength of polar and non-polar amino acids interacting with each other and water molecules drive protein folding?

Student responses: Polar amino acids interact more strongly with other polar amino acids and water molecules. non-polar amino acids also interact with polar amino acids and water but not as strongly, so they are forced out from between water and the polar parts of the protein molecule. So you can see that the polar hydrophilic ones are attracted to each other and the water, while the non-polar ones are forced to cluster together.

Use the snapshot questions below to create pictures of two different folded proteins that illustrate your answer to the question above.

9. [drawing prompt] Snapshot 1: Take a snapshot and add labels to show your understanding of how amino acids interact with each other and with the surrounding water molecules to cause the protein to form this shape.

Student responses: Student snapshots should include annotations that point out the position of hydrophilic (polar/charged) amino acids mostly on the outside where they are more strongly attracted to water than the hydrophobic (non-polar) amino acids, which end up on the inside of the protein away from the water. The non-polar amino acids are excluded from the polar ones because the attractive forces between the polar molecules (amino acids and water) is stronger than the attraction between the polar and non-polar molecules (or parts of molecules).

10. [drawing prompt] Snapshot 2: Take a snapshot and add labels to show your understanding of how amino acids interact with each other and with the surrounding water molecules to cause the protein to form this shape.

Student responses: Student snapshots should include annotations that point out the position of hydrophilic (polar/charged) amino acids mostly on the outside where they are more strongly attracted to water than the hydrophobic (non-polar) amino acids, which end up on the inside of the protein away from the water. The non-polar amino acids are excluded from the polar ones because the attractive forces between the polar molecules (amino acids and water) is stronger than the attraction between the polar and non-polar molecules (or parts of molecules).

11. The term "hydrophilic" means "water fearing." This definition works because it describes the overall behavior, but there is something misleading about it. Why doesn't "water fearing" correctly describe what is happening if you think about the forces between polar water and non-polar molecules?

Student responses: Non-polar molecules are attracted to polar molecules, but not very strongly. "Water fearing" implies that they are repelled by water or "afraid" of it.

12. What happens to the potential energy of the system as the protein forms a stable structure?

Student responses: The potential energy decreases.

13. Why is the potential energy higher when the protein is unfolded?

Student responses: If things are attracted to each other then the closer they are to each other the lower their potential energy. So, a folded protein allows for the different parts of the protein to come closer together, lowering the potential energy.

14. How can the idea that nature tends toward lower potential energy states explain why the polar and non-polar parts of the protein end up forming predictable structures?

Student responses: Potential energy gets lowered more when strongly attracted things get closer to each other. So, if nature tends toward the lowest potential energy, then you get that when the more strongly polar parts (hydrophilic amino acids and water) can get closest to each other. That causes the protein to form these kinds of structures.

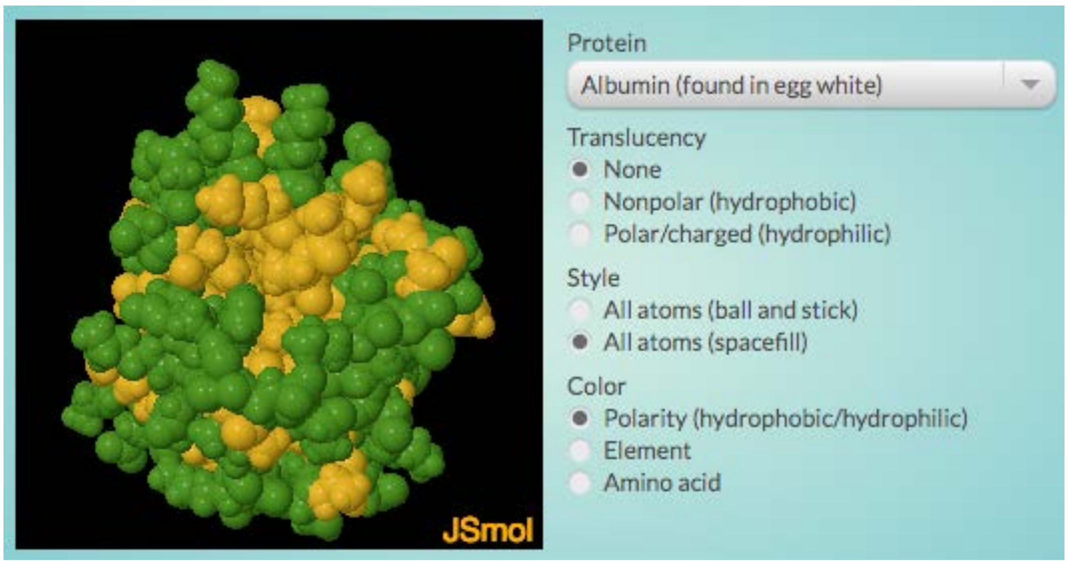
Discussion:
Ask students to share their answers to the questions above. Encourage them to think about how the structure of amino acids determines their properties and the resulting protein structure. Also, remind them to think how energy changes during protein folding.

Possible questions:

- What drives protein folding?
- What properties of amino acids determine the shape of proteins in water?
- If you had to predict which part of a protein would be on the outside and which part would be on the inside what would you consider?
- How does structure of amino acids relate to their properties and to the final protein shape in water?
- What happens to the potential energy of the system as the protein folds up? Where have you seen this pattern of potential energy and stability before?

Page title:
What do proteins look like?

The previous two simulations showed a simplified view of proteins (only two dimensional) to help illustrate certain folding patterns. The interactive below shows more realistic three dimensional protein structures. Explore these to see if you find similar patterns in how real proteins fold into stable structures.



https://lab.concord.org/interactives.html#interactives/interactions/exploring-hydrophobic-core.json

15. [drawing prompt] Take a snapshot that shows a pattern found in all of the proteins, showing how the protein folds and where polar and non-polar parts of the protein end up.
[text prompt] Explain why this pattern occurs by talking about forces and energy.

Student responses: You can see that the non-polar parts of the protein end up in the middle of the folded protein and the polar parts generally end up on the outside. This happens because of interactions with water molecules and the different forces of attraction that exist between the polar parts and non-polar parts of the protein with water. The polar parts have a stronger attraction, so they end up on the outside closer to the water which is also polar. Systems also tend to move in directions that lower their potential energy, and having the protein fold up this way causes the biggest decrease in potential energy. If non-polar amino acids were on the outside and coming between the surrounding water and the polar amino acids it would cause an increase in potential energy of the system making this an unfavorable structure.

Discussion:
Ask students to share their answers to the questions above. Encourage them to think about what each representation helps them understand about protein structure.

Possible questions:

- What are the pros and cons of each representation?
- How does the spacefill representation help you understand about the protein structure than others don't?
- What does ball and stick representation help you understand about the protein structure than others don't?
- What patterns do you see in how these proteins fold up?
- How are forces and energy related to those patterns?

Conclusion:
Revisit the driving question for the investigation "How are interactions with water important for maintaining my life?" Encourage students to think about how protein composition influences protein structure, and how protein structure is important for maintaining life.

Possible questions:

- How does protein composition determine its three-dimensional structure?
- How is protein structure maintained in water?
- Do you think the protein would still work if it folded up a different way?

Homework: Reading for Activity 1.3: What are proteins and why are they important?