Teacher's Preparatory Guide

Modeling Self-Assembly, Part I: *The Fly Prison*

How do scientists build something so small?

Purpose

The *Fly Prison* models how researchers build very small devices using the self-assembly of molecules. One researcher designed a fly prison to align flies so that tiny spots of metal could be adhered to the wings of the adult fly. The developing flies were provided with enough food to develop into adulthood on the drop of oil they were stuck to.

Level Middle school

Time required

Two 50 minute class periods or one 90 minute block day

Safety Information None.

Advance Preparation

Print enough student worksheets for each student to have his/her own. Prepare 8 packets (details below), but keep extra Velcro and index cards for future classes, because these materials should be changed after each use. (The red puff balls can be reused after removing the Velcro.) All other materials can be reused.

Each packet contains:

- a pencil
- a yellow pencil
- 6 red puff balls (1.0cm in diameter)*
- 6 small pieces of Velcro- the soft side (.5cm squares)*
- 6 larger pieces of Velcro-the stringy side (1.0cm squares)*
- an index card cut into a circle (7.5cm in diameter)*
- an index card that has been colored pink with six squares cut out (see image on the next page) (circle 7.5 cm in diameter, 1.0cm black squares)*
- a bottle of white-out
- a large sheet of butcher paper
- a set of cards that explain each item
- a keyring

*Sizes of materials can vary, as long as they fit together properly.

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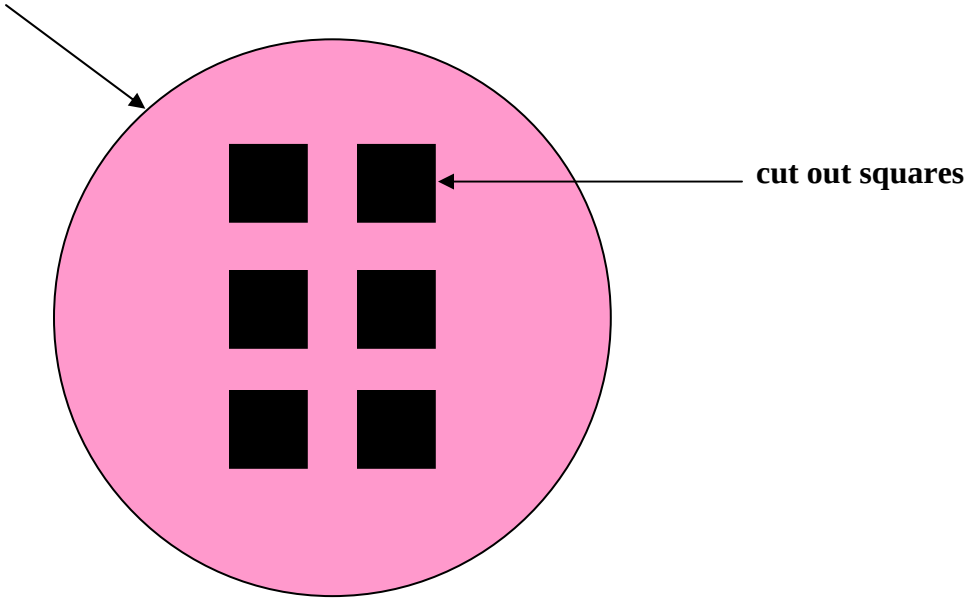
Template for Index Card

Index card with black squares cut out. This makes the mask:



Print 8 sets of description cards (next page) for each station and laminate the cards. Provide a piece of butcher paper for each group to brainstorm.

National Science Education Content Standards addressed

Content Standard A

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Content Standard B

- Structure and properties of matter
- Chemical reactions
- Motions and forces

Content Standard E

- Abilities of technological design
- Understandings about science and technology

Content Standard G

- Science as a human endeavor
- Nature of scientific knowledge

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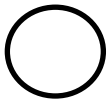
Description cards

Laminate the 2 pages of description cards and cut along the dotted lines. Punch a hole along the left side and attach to a keyring.

Red puff ball = fruit fly larvae Larvae are insects that have just hatched and are still growing. They do not have defined body parts, such as wings or legs. The fruit fly larvae has a neutral charge, so it will only stick to molecules that do not mix with water.

Pencil = Photoresist Photoresist is a paint-like chemical that is put on a silicon wafer. Photoresist weakens where ultraviolet (UV) light touches. A developer chemical (just like when developing film for a camera) washes away ONLY weakened photoresist. Developer does NOT wash away photoresist that has NOT been touched by UV light. Photoresist that has NOT been weakened by ultraviolet light prevents metals from sticking directly to the silicon wafer.

Yellow pencil = Gold Gold is a pure element that can melt (when it's hot enough and at a low pressure) and evaporate onto a silicon wafer (like water vapor does as it sticks to the lid of a pot) into a thin layer a few nanometers thick. Gold can form strong chemical bonds to sulfur hydrogen groups (SH) at the ends of molecules.



Circle of index card = Silicon wafer Resembling a CD, this wafer-thin piece of silicon (Si) has a layer of silicon dioxide (SiO_2) on it (like rust). Silicon wafers are made from purified sand that has been melted and slowly cooled in the shape of a cylinder. The cylinder is turned on its side and sliced (like cookie dough from a package) into paper-thin slices. The silicon wafer acts like a dinner plate—you will put everything on it.

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Index card with square holes = mask Have you ever had a sunburn? The skin burned where the ultraviolet light from the sun touched, and remained the same below the clothing. This is because the clothing blocked the ultraviolet (UV) light from touching the skin. A mask is a piece of glass with dark areas that prevent UV light from passing through. However, UV light passes through the clear areas.

Large Velcro squares = HDT molecules Each small string of Velcro represents one HDT molecule that is less than 2 nanometers (nm) long. Hexadecanthiol (HDT) are special molecules that look like long strings of carbon and hydrogen. One end of the molecule has a sulfur hydrogen group (SH). The other end has a carbon with three hydrogens (CH_3) and likes to stick to things that don't mix with water.

White-out pen = ultraviolet (UV) light The white-out pen should be used to show where ultraviolet (UV) light touches a wafer. UV light is used to change the properties of molecules or to remove molecules. UV light weakens photoresist in places that it touches.

Tiny Velcro square = drop of oil Oil has a neutral charge, so it does not mix with water, and sticks to other things that do not mix with water. This drop of oil is 100 micrometers (10^{-6} µm) wide

Eraser = solvent Solvent washes away all photoresist and any metal that is on top of the photoresist.

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Teaching Strategies
Divide students into groups of 4 to 5 students. Each group should work with one packet of materials. This lesson can be used after an introduction of molecules and their composition, and is designed to reinforce some simple interactions of molecules based on their polarity. The term *polarity* has been left out of this lab for the middle school level, but this background information is provided below for the advanced student:

- The fruit fly larvae is nonpolar.
- Gold deposits all over the wafer, even on top of the photoresist that was NOT touched by UV light (NON-weakened photoresist).
- NON-weakened photoresist is usually washed away in a laboratory by using a solvent such as acetone (found in nail polish remover) and isopropyl alcohol (found in many homes as rubbing alcohol.
- This lab talks about using a positive photoresist
- The SH group at one end of the HDT molecule forms a covalent bond with the gold. The other end is nonpolar (and it is *hydrophobic*, or water hating).
- The drop of oil is nonpolar.

This lab can easily be modified to become a high school level lab by speaking of the molecular interactions in terms of polarity.

Guided Dialog Use the guided dialog below to help introduce this activity to students:

- What materials would you need to build a sand castle? *shovel, bucket, water, sand*
- What might make a sand castle difficult to build? *Example answer: sand doesn't stick together, gravity, wind*
- Imagine if you could make a tiny castle that is much, much smaller than a grain of sand. (You may wish have a grain of sand at each station for effect.) How might you do this? *Sculpt or chisel the sand somehow down to a castle, or build a castle by using atoms or molecules as "bricks"*
- What problems might you have with building a castle by either of these methods? *Example answer: size of materials, what tools to use, seeing what you are doing*
- What if there was a way to entice the little castle to assemble all by itself? What would you call this method? *Answers will vary.*
- Some scientists face a similar problem when making devices. They use a method called *self-assembly* to build these devices. Define *self-assembly* in your own words. *Assembly means "to put together or to build"; self means "without outside help".*
- Do you know of anything that naturally "self-assembles"? (Hint: think of small things in biology) *cells and cell membranes*

How do engineers get molecules to self-assemble into devices? Here's their trick:

Molecules with like charges (++ or --) will repel (move away from) each other. Two negatively charged molecules, will move away from one another. Likewise, two positively charged molecules, will also move away from each other.

Molecules with unlike charges (+-) will attract. A positively charged molecule and a negatively charged molecule will move towards one another.

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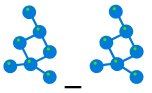
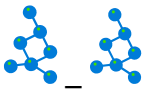
Molecules that are uncharged or neutral will congregate in a water environment because they are *hydrophobic* (water fearing). For example, oil consists of non-polar/uncharged molecules and will not dissolve in water, but form droplets or clusters of oil molecules. These oil molecules cluster together and stay away from the polar/charged water molecules that have both a negative end and a positive end. For the advanced student, explain: **Non-polar molecules repel polar molecules.**

Draw the molecules below on the board, and ask students what would happen:

 + *attract*

 *repel*

- What molecule would push a charged molecule away? *A molecule that is neutral, uncharged, hydrophobic, or non-polar, like oil.*

After the activity, review what part of building this fly model is self-assembly and the importance of manipulation to reach the desired goal.

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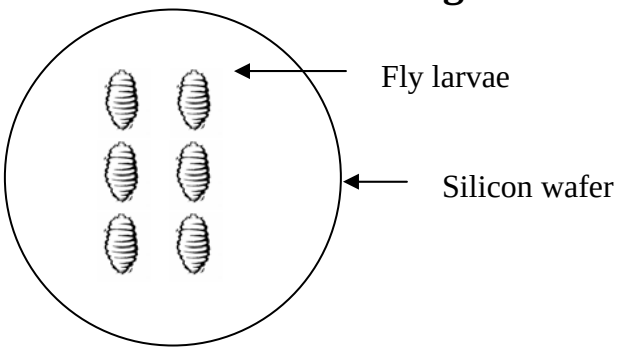
Student Worksheet with Answer Key
Modeling Self-Assembly, Part I: *The Fly Prison*



Your team has been hired by researchers to build a prison for fruit flies so that they can put a tiny transmitter onto each fly. These scientists want to attach a radio transmitter onto the back of the fruit fly. The catch is, you must use self-assembly to stick fruit fly larvae to a wafer, and the flies must be arranged as in the diagram at left:

Problem: How can our group create a fruit fly prison using only self assembly?

Making a stencil: Before you can rely on self assembly, you will model how scientists create a stencil to put the flies where needed.

1. Why will you use the index card as a base to put everything else on top of? *The index card represents a silicon wafer. It will be a base because silicon acts like a dinner plate.*

2. Completely (but lightly) color the index card with the plain pencil. What does the pencil represent? *The pencil represents photoresist.*

3. Put the card representing the mask on top of the circle representing the wafer. Where would ultraviolet light touch the photoresist? *The light would touch the photoresist on the areas that are not blocked off by the mask* Use the white-out to color the area where the light touches.

4. What happens when ultraviolet light touches the photoresist? *The light weakens the photoresist where it touches.*

5. Remove the mask. If the wafer is placed in developer, what would happen to the photoresist? Would all of it be washed away? Explain which area(s) would be washed away. (Hint: Review the photoresist card.) *Developer washes away only weakened photoresist, so only the white areas would wash away.*

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6. On the area(s) that were washed away, what is exposed? *The silicon wafer*

7. Add gold to your wafer by using the yellow pencil. Where will the gold be placed? (Hint: Review the card. How is gold put on the wafer?) *The gold will coat the entire wafer.*

8. If the wafer is now placed in a solvent, what would happen? Would all of it be washed away? Explain which area(s) would be washed away. (Hint: Review the solvent card.) *Solvent washes away all photoresist, even when there is metal on top, so the gold that is on top of the photoresist would would wash away.*

9. What area(s) would remain? *The areas where there was no photoresist would remain. So the 6 squares that have white out indicating that gold is stuck to silicon would stay.*

Use your eraser to show what the solvent would do to your wafer.

Checkpoint: Show your progress to your teacher before continuing.

Self-Assembly Write a procedure to the company that describes how to build a fly prison using self-assembly by filling in the chart below. Write down each step in order, and explain why each step is taken. **(Hint:** Look at the remaining cards. Which ones will bond together? Why?)

What will form bonds next?	Why?
HDT molecules bond to the gold (stick the large Velcro pieces to the gold)	*Gold can form strong bonds with SH groups, and HDT molecules have an SH group on one end.*
Oil bonds with HDT molecules (stick the small pieces of Velcro to the larger ones).	*The free end of the HDT molecule does not mix with water and sticks with other things that do not mix with water. Oil does not mix with water, so these molecules will stick together.*
The larvae bonds with the oil drops (stick the red puff balls to the sticky end of the small Velcro).	*The larvae is attracted to the oil, because neither has a charge.*

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Procedure Congratulations! You have built a model for how a scientist would test this in a laboratory. Now, write a procedure to the scientist that describes how to build a fly prison by filling in the chart on the next page. Be sure to use the terms that each part of your model represents. The first step has been done for you as an example. Be sure to explain why each step is taken.

Procedure	Why is this step taken?
1. *Use the silicon as a base.*	*Silicon acts like a dinner plate.*
2. *Cover the silicon wafer with photoresist.*	*Photoresist is a chemical that will help us form a stencil to put the fruit flies on.*
3. *Put a mask atop the wafer.*	*The mask will block UV light from touching certain areas of the photoresist.*
4. *Expose the wafer and mask to ultraviolet light.*	*The light will touch the photoresist on the areas that are not blocked off by the mask.*
5. *Dip the wafer (without the mask) in developer.*	*Developer washes away weakened photoresist, exposing only certain areas of silicon, while leaving the rest covered up.*
6. *Coat the wafer with gold/Evaporate gold onto the wafer.*	*Gold will cover the entire wafer.*
7. *Dip the wafer in solvent.*	*Solvent washes away all photoresist, even when there is metal on top, so the gold that is on top of the photoresist would would wash away.*
8. *Dip the wafer in a solution of HDT molecules.*	*Gold can form strong bonds with SH groups, and HDT molecules have an SH group on one end.*
9. *Dip the wafer in oil.*	*The free end of the HDT molecule does not mix with water and sticks with other things that do not mix with water. Oil does not mix with water, so these molecules will stick together.*
10. *Put the wafer near fruit flies.*	*The larvae is attracted to the oil, because neither has a charge.*

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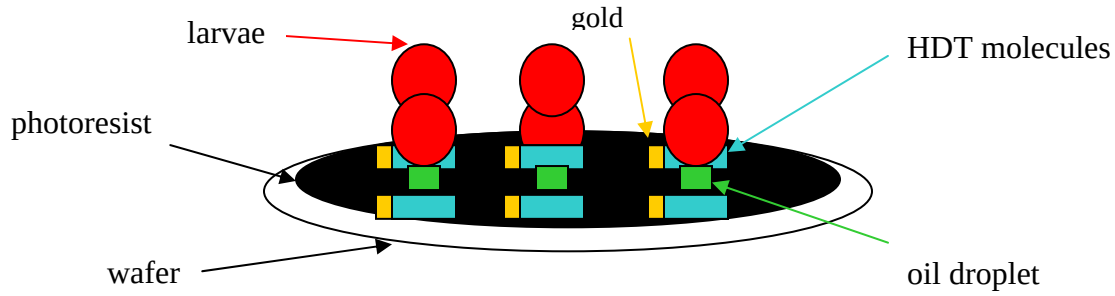
Draw a diagram of the final result with each item labeled so that the scientist can follow your instructions.



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