National Nanotechnology Infrastructure Network

Serving Nanoscale Science, Engineering & Technology

Teacher's Preparatory Guide

Using Modeling to Demonstrate Self-Assembly in Nanotechnology

How do scientists build something so small?

Purpose

There are two activities in this lesson, the *Fly Prison* and the *Water Maze*. The *Fly Prison* is a hands-on modeling activity designed to introduce students to the area of nanotechnology and give them a basic understanding of how researchers build very small devices by the self-assembly of molecules. The *Water Maze* is a follow up activity to give the students a chance to practice and demonstrate what they have learned.

Real World Uses: One researcher designed this fly prison to line up the flies in a perfect order, so that tiny spots of metal can be adhered to the wings of the adult fly. The developing flies were provided with enough food to develop into adulthood right on the drop of oil they were stuck to. As for water mazes, it has become a new field to develop on the spot lab testers that are the size of a credit card. A person can be in a remote place in the world and do quick tests by dropping blood or urine on one place on the card and the liquid is drawn through a series of channels providing indicators for certain things the researchers are looking for.

Level High school

Time required

Two 50 minute class periods or one 90 minute block day for the *Fly Prison* model

Two 50 minute class periods or one 90 minute block day for the *Water Maze* challenge question

Advance Preparation

For the Fly Prison: Each student will need a student worksheet/handout. For the groups, prepare 8 packets of the modeling materials from the list below and have additional Velcro and index cards for the following classes. (It is very important to know that the wafer (made of an index card) and Velcro must be replaced, before another group uses the materials. The red puff balls must have the Velcro removed from them, but they can be reused. The used wafer with the Velcro attached should be thrown away.) All other materials can be used over again. There also should be 8 sets of cards for each station.

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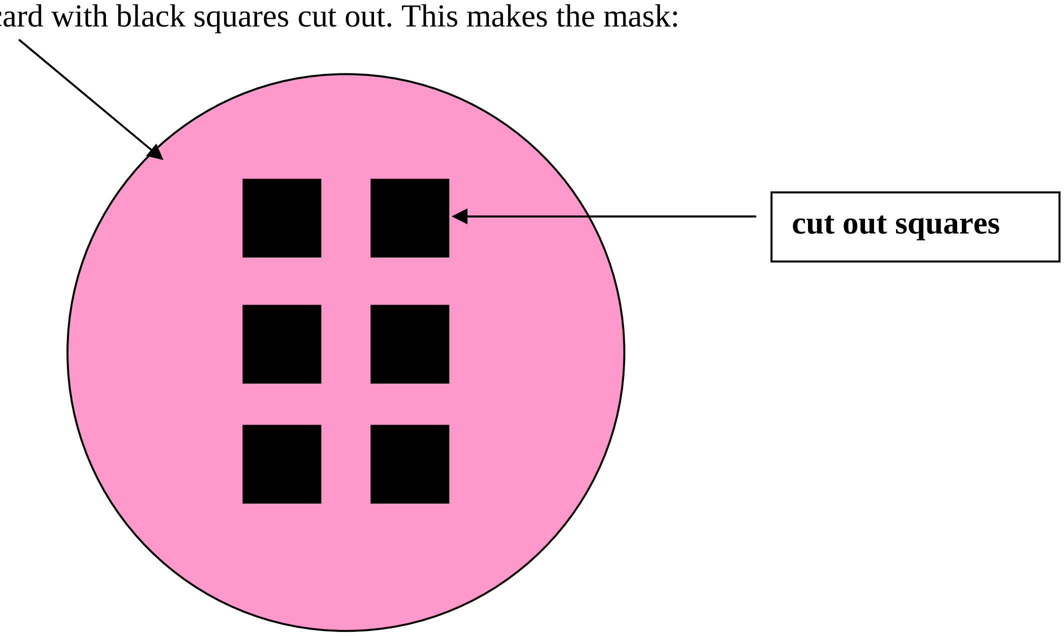
You can make copies, cut them out, laminate them and connect them together on a ring. It is advised to also include the list of "cards" for each student to look at with their packet. It makes it easier for all the group members to follow along, if one or two students in the group are not sharing the cards. Each group will need a fresh piece of butcher paper for brainstorming. At the end of the lesson, it is recommended to review what part of building this fly model is truly self-assembly and the importance of manipulation to reach the desired goal.

Each packet contains:

- one black marker
- one yellow highlighter
- six red puff balls (1.0cm in diameter)*
- six small pieces of Velcro- the soft side (.5cm squares)*
- six larger pieces of Velcro-the stringy side (1.0cm squares)*
- one index card cut into a circle (7.5cm in diameter)*
- one index card colored pink with six squares cut out (see below) (circle 7.5cm in diameter, 1.0cm black squares)*
- one bottle of white-out
- one sizable sheet of butcher paper
- one set of explanation cards of each item

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

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



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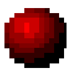
It is very important to remember that the wafer and Velcro must be replaced, before another group uses the materials. The red puff balls must have the Velcro removed from them, but they can be reused. The used wafer with the Velcro attached should be thrown away.

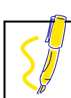
Cards to cut out and laminate:



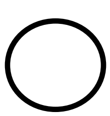
Red puff ball = fruit fly larvae The larvae is still developing and does not have defined body parts, such as wings or legs. It has a non-polar coating on the outside of its body. This force is not strong enough to attract to the SAM – self assembled monolayer, because the larvae are much larger and need stronger forces, such as capillary forces.

Small fuzzy square of Velcro = drop of oil This drop of oil is only 100 micrometers (10^{-6}m) in width. Remember oil is nonpolar!

Black marker = Photoresist This is a chemical that can be applied to the silicon wafer. When UV light is exposed to it, the Photoresist can be removed by a developer chemical (just like film for a camera). When Photoresist is present, it can prevent gold from depositing onto the silicon wafer.



Yellow highlighter = Gold Gold is a material that is pure and can be applied to the silicon wafer through a machine that uses what's called physical vapor deposition. This allows the gold to be applied one nanometer at a time. Gold also can easily covalently bond (strongly bond) to sulfur hydrogen groups (SH) in molecules.



Circle of index card = Silicon wafer This wafer is made of silicon with layer of silica (SiO_2) and it acts like a platform to build your device on. Silicon is a also the material that glass is made out of.

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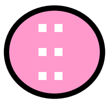
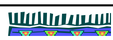


Index card with square holes = mask A mask is a device used to block out UV light in the dark areas and let the UV light through in the clear areas.



Large Velcro squares = HDT molecules Hexadecanthiol (HDT) organic molecules are long string-like molecules. In our model each small string of the Velcro represents one molecule. They are less than two nanometers (nm) long. One end has a sulfur hydrogen group (SH) on the bottom and the free end has a carbon with three hydrogens (CH_3) which means it is non-polar, and therefore hydrophobic. When many of these molecules bond to a surface in one layer by themselves it is called a self-assembled monolayer (SAM). **10. What does hydrophobic mean?**

White-out pen = UV light The white-out pen can be used to show the area that UV light touches the wafer. UV light is a tool that is used for changing molecules, by changing their property or removing them entirely.

For the Water Maze: You will need one water maze worksheet/handout for each group, and one piece of butcher paper and markers for each group. You may want to make copies of the rubric for each of your classes.

Safety Information
This is not a "wet" lab, so there are no safety concerns for students.

Teaching Strategies
This lesson on nanotechnology can be used after an introduction of molecules and their composition, and it is designed to reinforce some simple interactions of molecules based on their polarity.

When implementing the fly model activity, all students are given a lesson packet to read from and to write their work on. Students are set up into groups of 4 to 5 students. At their station, will be one set of the modeling materials. This is a guided inquiry activity, so there are check points, where the group must contact the teacher before continuing on.

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At this time the teacher reviews what the students have learned so far and can intervene if the students are off-track or confused. It is important not to give away too much, in order for the students to make discoveries for themselves.

The lesson is designed to be inquiry-based, so there is little preparation necessary for the students other than a basic introduction to molecules.

Before the activity, review with the students the following:

- What is nanotechnology? Where have you heard the word "nano" before?
- What is the difference between organic and inorganic molecules?
- How does the polarity of molecules affect how the molecules interact?

Nanotechnology is the science of building systems at the nano-level – very, very small ($1X10^{-9}$m). Nano is a term that is commonly being used in marketing products that are very small, such as the nano Ipod. Organic molecules include the element of carbon and are found in living things, which specialize in self-assembly (making more cells). Inorganic molecules are made of elements other than carbon and are usually found in the abiotic world. Most systems in technology are made from inorganic materials, but nanotechnology must turn to organic molecules as the building materials for electronic systems. Molecules that are polar avoid molecules that are nonpolar. Of the polar molecules, like charges repel and unlike charges attract. These interactions can be manipulated and relied upon for these tiny systems to self-assemble.

Student Handout with Answers

Using Modeling to Demonstrate Self-Assembly in Nanotechnology

How do scientists build something so small?

Imagine building a device that is small enough to fit on a contact lens. It has an antennae and a translucent screen across the pupil of the eye that allows you to see arrows giving you directions as you drive to an unknown destination. Imagine designing tiny monitors that are put into your blood stream to constantly check the levels of cholesterol or sugar. The information is readily available without taking any blood and can be used for early detection of heart disease or diabetes. These science fiction-like devices could soon be reality with the work of many researchers in the area of nanotechnology.

Nanotechnology is an area of study that integrates many disciplines, math, biology, chemistry, physics, computer science, engineering, and technology. Engineers using nanotechnology build devices that are very, very small. These devices are called Nanoelectromechancial Systems (NEMS). How small do you ask? Well, a nanometer is one billionth of a meter (10^{-9}m). To understand how small this is, look at your fingernails. You can't see them growing, but you know they are, because over time they get longer. The human fingernail grows approximately one nanometer (nm) per second! That's a very tiny amount! To build devices that are that small presents a great challenge. Consider the following:

1. What materials would you need to build a sand castle and what are some of the obstacles that would make it difficult for you to build it?

(shovel, bucket, water sand)

(obstacles: sand not sticking together, gravity, wind)

2. Now think about creating a castle that is only 10nm tall and 5nm wide, smaller than one grain of sand. What are some of the difficulties engineers must overcome in order to build these tiny devices?

(size of materials, what tools to use to build them, seeing what you are doing to create it)

So how do engineers do what seems to be magic? Well, instead of working with large amounts of materials, they must work with very small amounts…just a few molecules at a time. (You can see where the chemistry comes into play here.) But good knowledge of chemistry will only get you so far. Knowing molecules, their properties and behaviors, is only the beginning. There is no way that a person can physically build these devices by using their hands or a robot, so they must rely on "self-assembly."

3. What do you think "self-assembly" means?

(assembly meaning "to put together or to build", self meaning "without outside help or on its own)

You guessed it…the devices must build themselves. Of course, the devices will need some guidance from the engineer. So where do engineers get the tools to do this tiny work? They must look to the experts on self-assembly. What "experts" am I talking about?

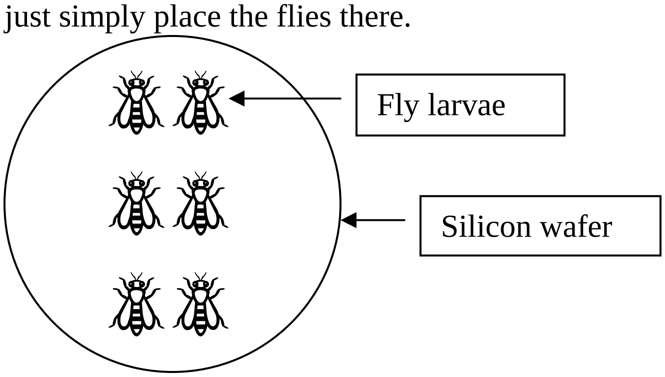
4. What is something that does its own "self-assembly" and creates a perfectly working "device"? (Hint: It is happening all the time, all over the earth.)

(Cells, biological systems create themselves by the interaction of molecules at the "nano" level)

*** Check Point: Raise your hand and have the teacher go over your progress so far.**

So biological molecules are studied by researchers in this field to see how they can be used to interact with inorganic molecules and serve as tiny parts of the NEMS. For example, DNA, a long string like molecule, is being investigated to be used as a possible wire when coated with gold. DNA is the organic biological molecule, and gold is the element that can actually carry the current of electricity. When you put the gold and DNA together, you get a wire that is "nano" size, in other words, very, very small.

YOUR TASK: Today your task will to make a model using self-assembly to create a fruit fly prison. You must arrange tiny fruit fly larvae (not quite developed fruit flies) in an orderly fashion stuck to a wafer. A wafer is similar to a microscope slide, but made of different materials and usually round in shape. It acts as a base for what you are working on. The ultimate goal of your research group is to be able to put a radio transmitter on the back of the fruit fly. In order to accomplish this, the fruit flies must be arranged on this tiny platform (the wafer) in a very exact spot. Your fruit flies must be arranged as shown in the picture below. The catch is that you must use self-assembly. You cannot just simply place the flies there.



So how do engineers manipulate molecules to self-assemble into the devices they want to create? Scientist must rely on how molecules naturally attract to one another by their physical properties and use this attraction to their advantage to step by step manipulate the molecules' behavior.

Consider the following:

5. Why do you go to the fair or an amusement park?

(rides, eat, play games, see livestock shows)

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Just like you are enticed by the delicious food and fun rides, molecules have preferences and we must entice them. Here are some rules to remember about molecules:

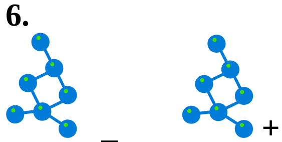
1. Polar molecules with like charges (++ or --) will repel (move away) from one another. For example, if there are two negatively charged molecules, they will move away from one another. If there are two positively charged molecules, they will also move away from each other.

2. Polar molecules with unlike charges (+-) will attract (move towards) to one another. For example, if there is one positively charged molecule and one negatively charged molecule, they will move towards one another.

3. Non-polar molecules (uncharged or neutral) will congregate with one another in a water environment because they are hydrophobic (water fearing). Non-polar molecules repel polar molecules. For example, oil consists of non-polar molecules and will not dissolve in water, but form droplets or clusters of oil molecules. These non-polar molecules are clustering together and staying away from the polar water molecules that have both a slightly negative and positive end.

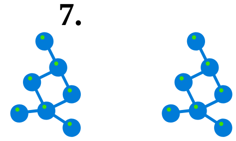
Look at the following examples below. On your paper, decide whether the two molecules will attract or repel.

6.



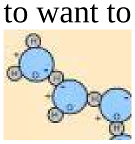
_ + (attract)

7.



_ (repel or not react at all)

Tiny forces resulting from these attractions, such as capillary action and surface tension, are also important to engineers because these forces are needed for a device to self-assemble. For example, water is a molecule that has a slightly negative end (the oxygen end) and a slightly positive end (the hydrogen end), which allows these molecules to want to stick to one another. These attractions are called hydrogen bonds.



This attraction causes a tiny force, called surface tension. This force can be very powerful. Some insects use this to their advantage, such as a water glider that slides across the surface of the water. Engineers use this force to their advantage. Water molecules are able to push non-polar molecules into groups. You will find surface tension useful in building your fly prison.

8. What molecule would push a polar (charged) molecule away? (Non-polar (oil))

*** Check Point: Raise your hand and have the teacher go over your progress so far.**

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Let's look at the materials at your desk! Go through the following items below and read aloud about each item to the group. (There is a card for each one.) As one person reads, have another person write about it on the butcher paper. <u>Write what the item is and what can be attracted to it or what its function is. Look for connections!! See below for an example.</u>

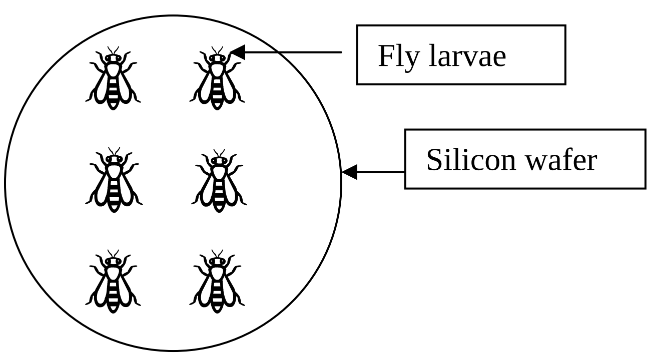
Butcher Paper

Wafer
-made of silicon

Gold – yellow highlighter
-sticks to silicon
-can covalently bond to SH groups

*** Check Point: Raise your hand and have the teacher go over your progress so far.**

Now that you have discussed the connections between the modeling tools, decide how to build your fly prison, step by step.
REMEMBER: Your goal is to put the fly larvae on the wafer as shown in the picture below by self-assembly.



9. Write down step by step your plan of attack and write why you are taking each step, by filling in the provided chart.

Procedural Step of Assembly:	Why you are taking this step?

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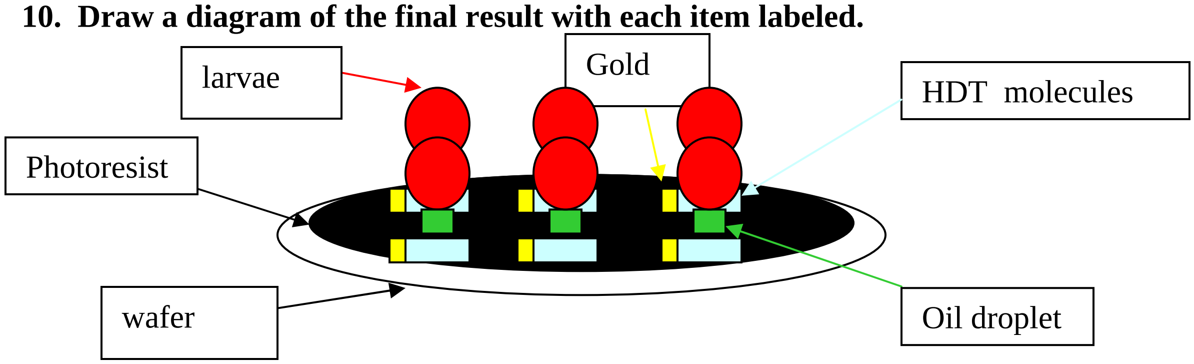
1. Color the wafer completely with the black marker.	Putting Photoresist all over the wafer is a beginning step to make a "stamp" for the areas where gold is needed.
2. Use mask to white-out the areas where the black shows through the holes.	This allows you to remove the Photoresist in specific spots by the UV light.
3. Color over the white-out with yellow highlighter.	The gold will stick to the wafer only where the silicon is exposed.
4. Stick the large Velcro pieces to the gold (the yellow highlighted regions).	HDT molecules to covalently bond to the gold and make available its non-polar ends.
5. Stick the small pieces of Velcro to the larger ones.	The oil attaches to the non-polar end of the HDT molecules.
6. Stick the red puff balls to the sticky end of the small Velcro.	The larvae is attracted to the oil, due to being both non-polar.

When you have agreed on your steps, go ahead and build your prison with the items given.

10. Draw a diagram of the final result with each item labeled.



11. Now show your model to the teacher. Congratulations on making your fruit fly prison!

Teacher preparation for the water maze/challenge question:

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The water maze activity (challenge question) should be given right after, or the day after, the fly prison modeling activity and the students will need the lesson packet for information. I would recommend beginning the lesson by reviewing how they decided to put together their fly prison to remind them of their first task and why they took each step that they did. Provide students with the cards from the modeling lesson packet and the new handout, markers and butcher paper.

The actual handout for the water maze/challenge question is designed for one per group. The grading of this activity is done by the teacher when the group presents. Every student in the group must have a speaking part and below is a very basic grading rubric that can be easily modified to fit your style. Directions for the presentation are on the worksheet.

Group members	Basic Understanding of Self-Assembly	Creativity in Design	Basic Understanding of the attraction of molecules
Score:			

Final Score:___________

Comments:____
____
____
____

The rubric could be much more specific, but these are three basic objectives of the question. Hopefully, this will inspire those who like to create and build, towards a career in engineering at the "nano" level. This question was not made to have one correct answer, but just to get students to create, think, and ask questions.

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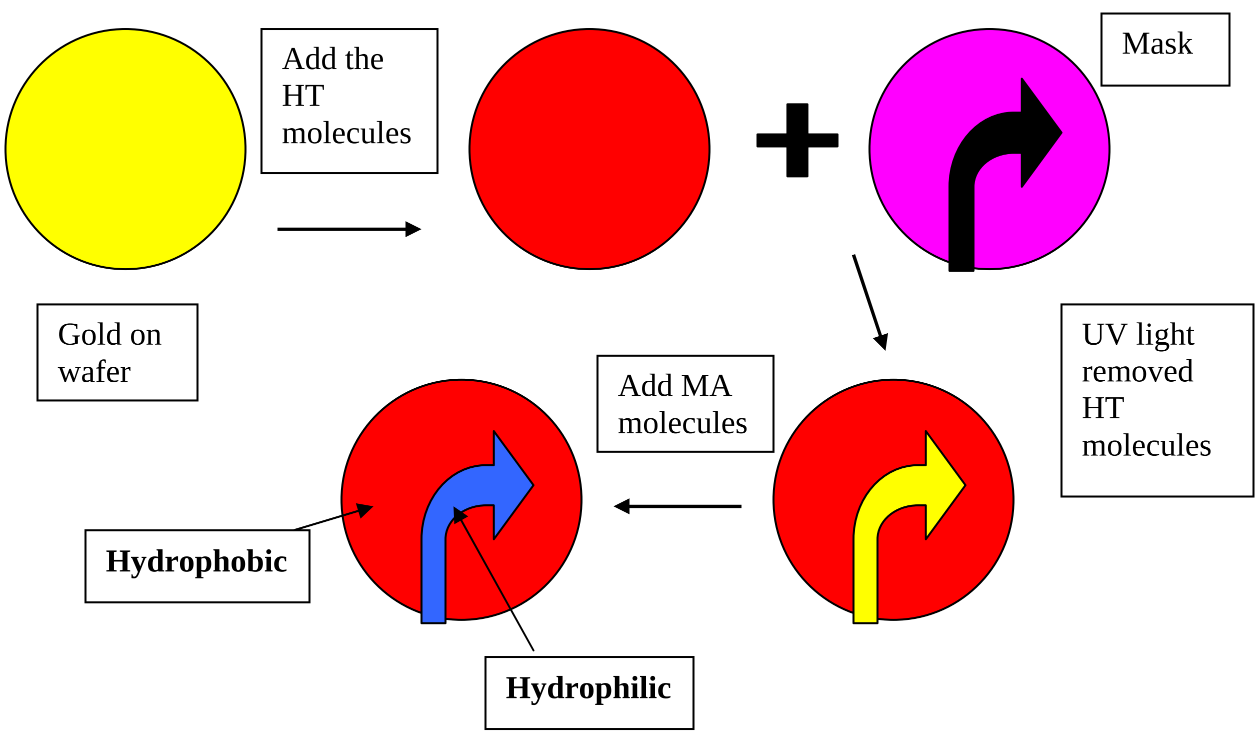
One possible answer to the challenge question could be as follows:

Procedural Step of Assembly:	Why you are taking this step?
1. Add gold to the entire wafer.	The gold will be used for the monolayer to form on the wafer.
2. Cover the gold with the HT molecules.	This makes a hydrophobic SAM.
3. Use the mask (below) and UV light to "cut" away the HT molecules in the area of the desired water path.	Gold is exposed only where the water path will be made.
4. Add the MA molecules to the wafer, where the gold is exposed.	MA molecules will be able to covalently bond to the gold pathway.
5. Submerge the wafer in water.	The water is able to move through the maze.



Reasoning for design: The water molecules are attracted to MA molecules and will move up the path by capillary action. The HT molecules are hydrophobic and will repel the water molecules, keeping the water in the desired path.

This scenario is only one possibility. To actually have a dynamic system such as this would be truly much more complicated. So students can be insightful in that this problem has many challenges and would need more techniques and tools than given to accomplish this goal.

National Science Education Content Standards addressed – Grades 9-12

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