

# How Can I Design Something to Build Itself?

## Self-Assembly at the Nanoscale

Author: Shanna Daly  
Draft Date: 4/30/2008

Content Area: Biology, Chemistry, Physics  
Grade Level: 7-12

### LESSON OVERVIEW

**Estimated Time of Lesson: 3.5 hours**

#### Lesson Description

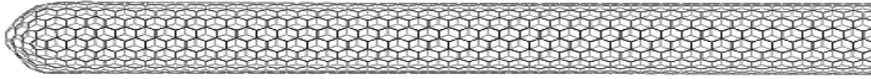
- Topic: Factors that affect self-assembling systems, design
- How the topic is contextualized: Real examples of self-assembly
- Importance of the topic: Factors that impact self-assembling systems impact any nano system. Understanding what it means to design and apply technical knowledge to a design is a basis for understanding much of the work of nanoscale scientists and engineers.
- Connection of the topic to other science concepts: Factors that impact self-assembly are factors that impact systems in general, including intermolecular forces, energy (temperature), sterics, environment, concentration, etc.
- Description of what the students will do to investigate the topic: Explore factors impacting self-assembly using models and utilizing the technical knowledge gained to design an optimal system.

#### Learning Goals

- Students will be able to discuss the complexity of potentially self-assembling systems and a number of factors that impact these systems, specifically charge orientation and location, shape, energy/ temperature, environment, complexity of system, including number of different components.
- Students will have an awareness of the nature of design, specifically design of components and systems at the nanoscale.
- Students will be able to compare approaches for building nanoscale complexes/ systems.

#### Big Ideas in Nano

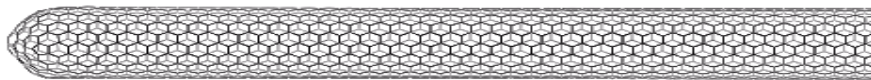
- Self-Assembly: Under certain conditions, some materials can spontaneously assemble themselves into organized structures at a lower equilibrium state. This process provides a useful means for manipulating matter at the nanoscale.
  - How this lesson relates to the big idea: This lesson allows student to investigate the process and definition of self-assembly.



- Forces: All interactions can be described by multiple types of forces, but the relative impact of these forces change with scale. On the nanoscale, a range of electrical forces with varying strengths tend to dominate the interactions between objects.
  - How this lesson relates to the big idea: This lesson explores the forces that dominate the process of self-assembly.
- Models: Models help us understand, visualize, predict, hypothesize and interpret data about natural and manufactured nanoscale objects and phenomena, which by their very nature are too small to see.
  - How this lesson relates to the big idea: Students use models to investigate properties of nanosystems and create a model of self-assembly to further understand the process and the nature of design.

## Standards

- NSES National Standards
  - Grades 6-8
    - Content Standard A
    - Content Standard B
  - Grades 9-12
    - Content Standard A
    - Content Standard B
    - Content Standard C
- Benchmarks National Standards
  - Grades 6-8
    - 4D: 1.2
    - 4D: 3.1
  - Grades 9-12
    - 4D: 9.2
    - 4G: 2.1
    - 8B: 4
- Indiana State Standards
  - Grade 7
    - 7.7.3
  - Grade 8
    - 8.2.7
    - 8.3.8



- 8.3.10
- 8.3.18
- 8.7.1
- Chemistry
  - C.1.36
- Integrated Chemistry/Physics
  - CP.1.11
  - CP.1.28

## LESSON PREPARATION

### Teacher Background Content Knowledge

- Intermolecular forces
- The impact of temperature on energy
- The nature of models in science and engineering
- Basic understanding of the nature of design

### Student Prior Knowledge Expectations

- Particles can be charged positively and negatively. Opposite charges attract.

### Potential Student Alternative Ideas

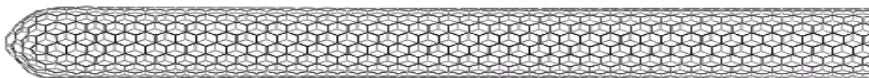
- Magnetic attraction is synonymous with electrostatic attraction.

### Potential Student Difficulties

- The following concepts may need clarification after use of this model:
  - An external force in this activity is the physical shaking of the box by students. On the nanoscale, molecules are constantly in motion. Motion is constant on the molecular level.
  - Molecules are more flexible than rigid Legos.
  - Components are not “locked” in forever on the molecular level. Changes in conditions could cause disassembly. In the Lego model, if the box is shaken hard enough, components may disassemble, but most of the time they will stay locked together. Showing the self-assembly computer visualizations support this concept.

### Materials

Item	Number/Amount
Computer	1 per student



Colored Sand/ Colored Sprinkles (3 different colors)	1 tablespoon of each color/ two students
School glue	1 per two students
Boxes (Clear plastic or cardboard) at least 10 in x 10 in x 10 in	One per student
Premade LEGO systems (described below)	5 systems
LEGOs (medium sized) or blocks of a similar size	~10 per student
Superglue	1 tube per student
Velcro tape	~5 inches per student
Magnets (~1 cm diameter) Strong ones needed, ordered from Edmund Scientific 3042582 Shape: Disc, Size: 3/8", Thickness: 1/4", Lift: 2 oz., Comments: Ceramic 1 Magnetized Side: Largest Area, Quantity: 100	~10 per student
Masking tape	1 roll per student

### **Cautions/ Potential Pitfalls**

- Lego systems must be premade by the instructor with time for the glue to dry.
- The self-assembly model that students make should be designed on paper first, and then constructed without gluing the magnets on. The teacher can control this by only providing the legos and magnets and having students present their designs to the teacher to acquire their glue.

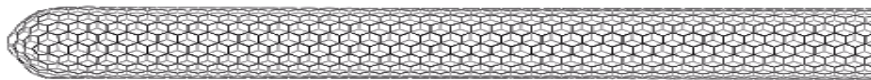
### **Pre-Class Preparation**

#### **Getting the Materials Ready**

- Find computers with Java capabilities that have internet access.
- Provide students with basic directions on how to use the computer.
- Cardboard cookie-cutters should be made of the shapes in the sand template.
- Have kits prepared with 5-15 legos or blocks (depending on preferred complexity), Velcro strips, magnets, masking tape for the design portion of the lesson. Hold back the glue until you have approved students' design.

#### **Safety Issues**

- Superglue is relatively strong and fingers could be glued together.



## DOING THE LESSON

### Opening

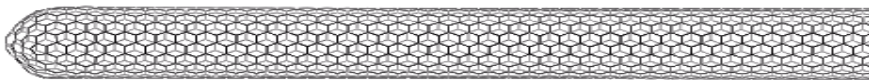
- Building with Sand (gets at top-down vs. bottom-up learning goal)
  - Students are put into groups of four, and further divided into teams of two. This is so each team can see what the opposite task entails.
  - There is a pattern on a piece of paper (like a color by number with colored sand) [see worksheet titled “Building with Sand” at the end of this lesson].
  - Teams are challenged to build their sand structure given specific requirements of their task. One team of two has task 1, building the pattern sand piece by sand piece (top-down analogy), while the other team has task 2 and can utilize a cookie-cutter-type tool to control the environment (bottom-up analogy).
  - Once students have worked on their task for 5-10 minutes, the instructor should engage the students in reflection and discussion. The following questions are suggested?
    - What was the difference between the two tasks?
    - How difficult was it for each group to build their template as directed?
    - Which approach do you think would be considered “top-down”?
    - Which approach do you think would be considered “bottom-up”?
    - Does the size of the particle influence how easy or hard it is to build “top-down” vs. “bottom up”?
    - What happens if the particles were smaller than grains of sand? Is it possible to place each piece exactly where you want it to go?
    - Can you think of an efficient way to build something so small in an accurate way?
- Provide 2 or 3 examples of self-assembling systems (1- DNA origami; 2- micelle; 3- monolayer) with a summary, picture, and news article about the phenomenon [See supplementary materials].
  - Ask: What kinds of things may impact this system building itself from the bottom-up?
  - Questions on the act of designing
    - How are systems designed?
    - What does it look like to design?
    - What obstacles might scientists and engineers face when they design?
- Tell students they are going to investigate some potential factors through the use of some self-assembly models (computer and manipulatives).

### Body

#### Activity 1 – Stations Investigating Factors that Impact Self-Assembly

##### 1. Experience

- a. Students spend 10 minutes at each of five stations and answer questions from their worksheet using the models to investigate. The stations have a pre-built model and some of them have a molecular workbench computer



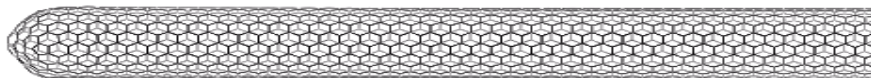
page as well. (See attached worksheet for detailed questions about each station.) The molecular workbench pages can be found by going to the following website:

<http://www.concord.org/publications/newsletter/2005-fall/friday.html>

- b. Stations allow students to specifically investigate these factors:
    - i. Charge orientation and location
    - ii. Shape
    - iii. Energy/ temperature
    - iv. Environment
    - v. Complexity of system, including number of different components
  - c. Students should discuss the questions for each station with others at the station and then spend a few minutes writing their own personal answer on the worksheet.
2. Making Sense
- a. Group discussion of factors and questions investigated at each station.
    - i. Go through each station and ask students to share some of their responses.
    - ii. As a follow-up to the station questions topics, some concepts to make sure that are addressed include:
      1. How does the location and type of charge impact the system?
      2. Do some molecules “fit” better with each other?
      3. What environmental factors might influence the system?
      4. How is the temperature of the system “simulated” with the models? How does the temperature influence the system?
      5. How would you predict the concentration of a component would impact the system?
      6. With our models, the number of components in the system made it more difficult for assembly to happen. What does that make you think about how incredible it is for nature to assemble multiple components made of smaller components?
  - b. Discussion of the models as macro objects and how those are easier to build top down vs. bottom up but they used to represent a world we cannot interact with top down.

### **Activity 2 –Design Your Own System**

1. Students are then provided with a box of Legos or blocks, velcro, magnets, and masking tape and challenged to design a model of a self-assembling system. They should present their model ideas to the instructor before given glue.
2. After the students have designed their self-assembly system, they can test the process in a clear or cardboard box. As a group discussion, students should critique their models and discuss the complexity of design.



## Wrap-up

- Students should be led in a discussion on what factors impact self-assembly, what it means to design, applying knowledge learned of factors and the practice of design to student-made systems, and the use of models to investigate nanotopics.

## Assessment

- Formative Assessments Table

Assessments	Where in lesson	Possible correct responses
Design reflection	Opening	
Top-down vs. bottom-up comparison	Opening	
Stations Worksheets	Body	

- Summative Assessment (Post-lesson assessment)
  - Back to context of systems introduced at opening and have students discuss factors and their impact on those systems

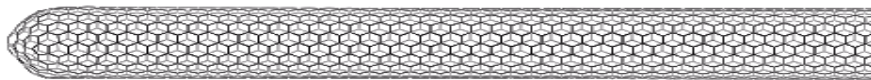
## ADAPTATIONS

- Extensions
  - What is gained from this?
- Simplifications
  - How do the learning goals change?

## RESOURCES

Lesson plan information related to the Molecular Workbench simulations was designed by the Concord Consortium: <http://www.concord.org/>.

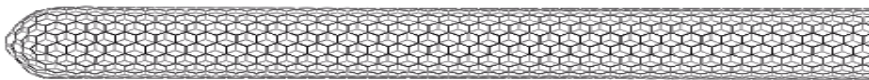
Lesson plan information related to the use of Legos, magnets, and Velcro to design a self-assembling system was inspired by the lesson plan created by the UNC-Chapel Hill College of Education.



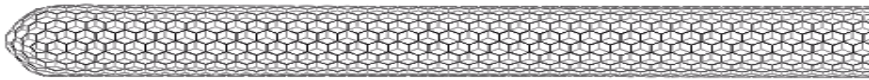
## **SUPPLEMENTAL MATERIALS**

### Standards

- NSES National Standards
  - Content Standard A: As a result of activities in grades 5-8, all students should develop
    - Abilities necessary to do scientific inquiry
    - Understandings about scientific inquiry
  - Content Standard B: As a result of their activities in grades 5-8, all students should develop an understanding of
    - Motions and forces
  - Content Standard A: As a result of activities in grades 9-12, all students should develop
    - Abilities necessary to do scientific inquiry
    - Understandings about scientific inquiry
  - Content Standard B: As a result of their activities in grades 9-12, all students should develop an understanding of
    - Structure and properties of matter
    - Motions and forces
  - Content Standard C: As a result of their activities in grades 9-12, all students should develop understanding of
    - Matter, energy, and organization in living systems
- Benchmarks National Standards
  - Grades 6-8
    - 4D: 1.2: Atoms may stick together in well-defined molecules or may be packed together in large arrays. Different arrangements of atoms into groups compose all substances.
    - 4D: 3.1: Atoms and molecules are perpetually in motion. Increased temperature means greater average energy of motion, so most substances expand when heated.
  - Grades 9-12
    - 4D: 9.2: Some atoms and molecules are highly effective in encouraging the interaction of others.
    - 4G: 2.1: Electromagnetic forces acting within and between atoms are vastly stronger than the gravitational forces acting between the atoms.

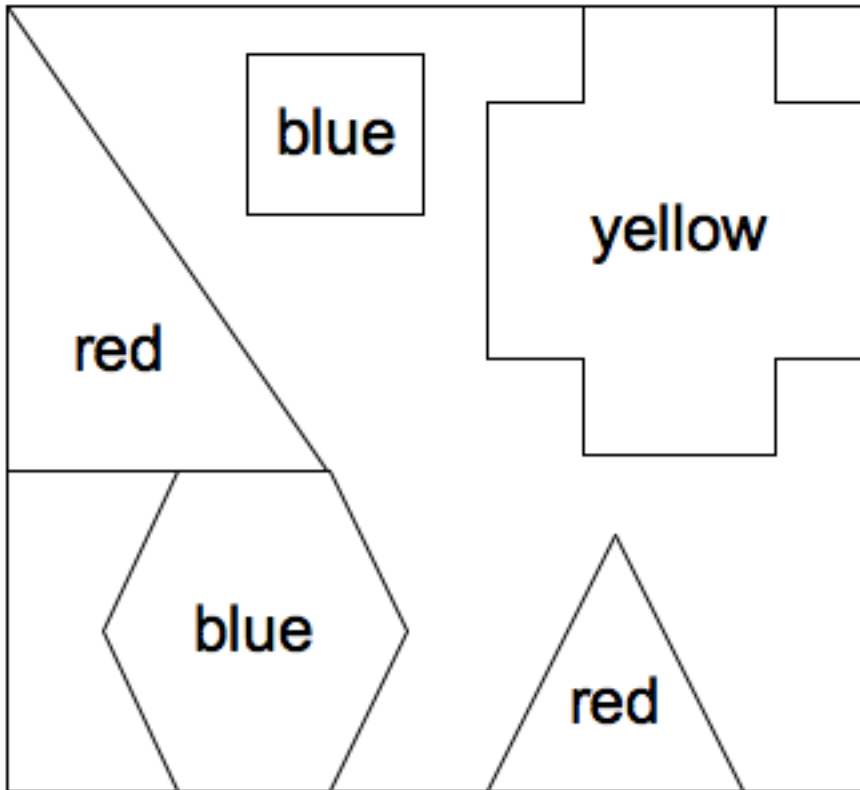


- 8B: 4: Increased knowledge of the molecular structure of materials helps in the design and synthesis of new materials for special purposes.
- Indiana State Standards
  - Grade 7
    - 7.7.3: Describe how physical and biological systems tend to change until they reach equilibrium and remain that way unless their surroundings change.
  - Grade 8
    - 8.2.7: Participate in group discussions on scientific topics by restating or summarizing accurately what others have said, asking for clarification or elaboration, and expressing alternative positions.
    - 8.3.8: Explain that all matter is made up of atoms which are far too small to see directly through an optical microscope. Understand that the atoms of any element are similar but are different from atoms of other elements. Further understand that atoms may stick together in well-defined molecules or may be packed together in large arrays. Also understand that different arrangements of atoms into groups comprise all substances.
    - 8.3.10: Explain that increased temperature means that atoms have a greater average energy of motion and that most gases expand when heated.
    - 8.3.18: Investigate and explain that electric currents and magnets can exert force on each other.
    - 8.7.1: Explain that a system usually has some properties that are different from those of its parts but appear because of the interaction of those parts.
  - Chemistry
    - C.1.36: Describe the nature of ionic, covalent, and hydrogen bonds and give examples of how they contribute to the formation of various types of compounds.
  - Integrated Chemistry/Physics
    - CP.1.11: Understand and give examples to show that an enormous variety of biological, chemical, and physical phenomena can be explained by changes in the arrangement and motion of atoms and molecules.
    - CP.1.28: Realize and explain that electromagnetic forces acting within and between atoms are vastly stronger than the gravitational forces acting between atoms.

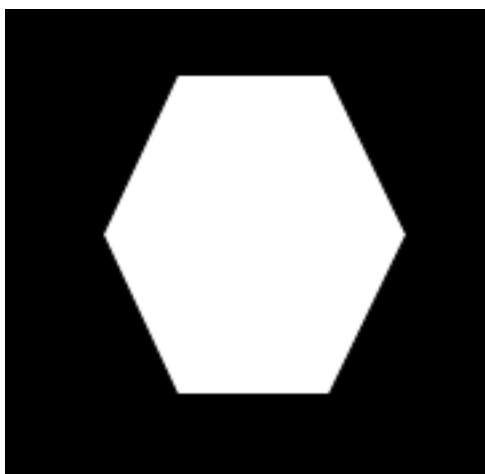


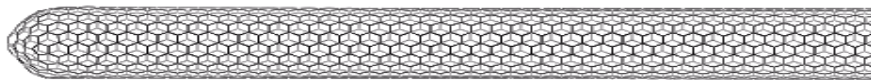
### Building with Sand

The following pattern is given to students. (This pattern can be adapted to whatever shapes are desired.)



Prior to the lesson, the shapes in the template should be made into cookie-cutter-type tools for task two. For example (the black is the cardboard and the white has been cut out):

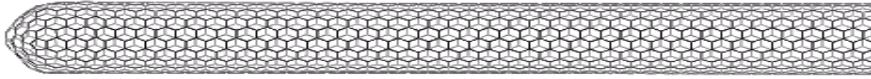




Groups of two will receive one of two tasks.

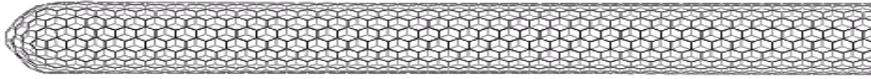
Task one: Spread glue on your template. Fill in the template as the specified with colored sand. You must place each grain of sand piece by piece. Do not put more than one grain of sand at a time on the template.

Task two: Spread glue on your template. Fill in the template as specified with colored sand. Utilize the “cookie-cutter” cardboard shapes to control where the colored sand goes on your pattern as you pour it.



## **Real Self-Assembling Systems**

This worksheet should have three short articles on real self-assembling systems. You can find these on the internet. Recommended systems are DNA origami, micelles, and monolayers (like metal rubber). If you need articles and cannot find them, please contact the lesson designer at [sdaly@purdue.edu](mailto:sdaly@purdue.edu).



## Station Questions

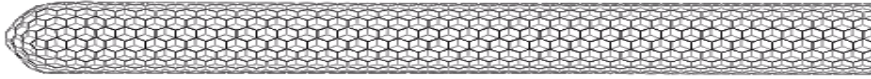
At each station, follow the directions for interacting with the model or models. Discuss the questions within your group and write your answer in the space provided.

Station 1 : Consider the following 3-D and computer model. Separate the lego pieces and shake them around in their box lid environment. Follow the directions on the molecular workbench page.

1. What factor(s) have an influence on the self-assembly of these models?
2. How do each of the factors impact the system?
3. If you wanted to design your own self-assembling system, how would you optimize these factors?

Station 2: Consider the following 3-D and computer model. Separate the two pieces of the lego model. Shake the components in their environment. Follow the directions on the molecular workbench page.

1. What factor(s) have an influence on the self-assembly of these models?
2. How do each of the factors impact the system?
3. If you wanted to design your own self-assembling system, how would you optimize these factors?

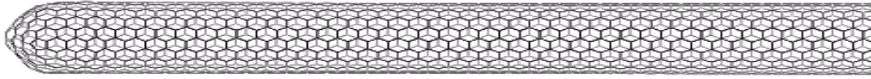


Station 3: Consider the following 3-D and computer model. Separate the lego pieces and shake them at different speeds. Consider the speed of your shaking when answering the questions. Follow the instructions on the molecular workbench page.

1. What factor(s) have an influence on the self-assembly of these models?
2. How do each of the factors impact the system?
3. If you wanted to design your own self-assembling system, how would you optimize these factors?

Station 4: Consider the following 3-D and computer model. Separate the lego pieces and shake them in the different sized box lids. Consider the lid size in answering your questions. Follow the directions on the molecular workbench page. Consider the environmental factors that you control on the molecular workbench page.

1. What factor(s) have an influence on the self-assembly of these models?
2. How do each of the factors impact the system?
3. If you wanted to design your own self-assembling system, how would you optimize these factors?



Station 5: Consider the following 3-D and computer model. Separate the lego pieces and shake them in their box environment. Design your own system with a few number and a large number of components on the molecular workbench page.

1. What factor(s) have an influence on the self-assembly of these models?
2. How do each of the factors impact the system?
3. If you wanted to design your own self-assembling system, how would you optimize these factors?