

Tall, Short, Thick, and Thin: They're all Models

Why are models and modeling important tools in science, engineering, and education?

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Content Area: General Science, Biology,
Chemistry, Physics

Draft Date: February 18, 2007

Grade Level: 7-12

LESSON OVERVIEW

Estimated Time of Lesson: 4 hours

Lesson Description

Topic: The role of models and modeling in science, engineering, and education

How the topic is contextualized: Contextualized as a tool that science and engineers use to advance their fields as well as a tool in education to help explain “unseeable” concepts to others

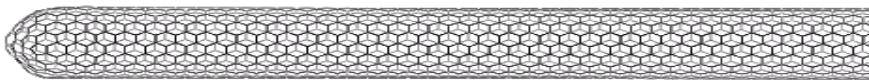
Importance of the topic: Models are crucial in science and engineering as tools to communicate, investigate, develop, and express ideas. They can also play a similar crucial role in education beyond just a tool for “show-and-tell”. This role is even more important to scientists, engineers, and educators when working with phenomena at the nanoscale.

Connection of the topic to other science concepts: Models are vital tools in many aspects of science and engineering.

Description of what the students will do to investigate the topic: Students will investigate models of many types used for many purposes, answer questions about phenomena the models represent, and evaluate their significance.

Learning Goals

- Students will be able to...
 - Describe a variety of different types of models.
 - Make a case that multiple models often create a more complete understanding of a phenomena since no one model is completely accurate.
 - Critique the accuracy of models and explain how models are still useful even with their inaccuracies.
 - Explain how models are tools used and designed in science and engineering to help conceptualize ideas, answer questions, hypothesize how something works, communicate to others, investigate properties, etc. (models as part of NOS and NOE; design of models).



- Describe the multiple uses of models, with emphasis that models can help us answer questions and are useful beyond a “show-and-tell” tool.
- Synthesize an argument for why models are especially important to the fields of nanoscale science, engineering, and technology.
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- In addition to achieving student learning goals, teachers completing the extension to this lesson will be able to...
- Design instruction that utilizes models of different types, multiple models, models as tools for investigation, the design of a model to represent a phenomenon.
- Make an argument with evidence for why multiple models can limit student misconceptions, how models play a role in the nature of science and engineering, how to utilize models in instruction as tools for investigation, how to limit student misconceptions created with models, why student-designed models are tools for student understanding as well as teacher understanding of student ideas.

Big Ideas in Nano

- **Models and Modeling:** 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.
 - This lesson emphasizes the broad range of model types in existence, and how these models are used to understand, visualize, predict, hypothesize, and interpret.

Standards

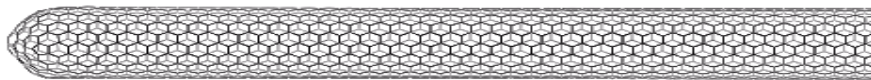
- Indiana State Standards
 - 7.1.7
 - 7.7.2
 - 8.1.6
 - 8.1.8
- Benchmarks
- 6-8: 11B
- Benchmarks
- STS 5-8

LESSON PREPARATION

Teacher Background Content Knowledge

This is an interesting area because models are used in science and engineering all of the time. There are a number of model types and purposes and recognizing the role of models, as tools and representations, can bring about the realization that models are not the real phenomena, but can help us understand and predict something more about an object or phenomena.

Models typology included in supplemental materials.



Student Prior Knowledge Expectations

Often students conceive of models as accurate representations of an object or phenomena. They also often do not recognize that models are useful beyond a show-and-tell format. It is expected that they will come in with this knowledge that is not necessarily incorrect, but is certainly limited in the ways that models are used by scientists and engineers.

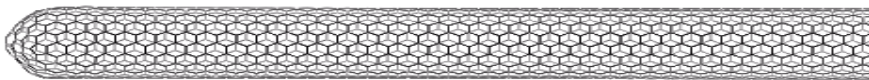
Materials

Item	Description/ Explanation
Concrete Material Static Model	A concrete models means that the model is not a drawing. It is a concrete object. Visual pictorial models can be drawings, figures or computer animations or simulations. A gestural bodily model is something that you use your hands or body to "act out." Static means the model is not manipulative. Dynamic deterministic means that the model is moveable but it always moves in the same way. You do not input some kind of action or information and get a response dependent on that action or information. A dynamic stochastic model is a model that responds based on the information that has been inputted. For example, if temperature information is inputted into a computer animation, the animation would change in response to the inputted temperature.
Concrete Material Dynamic Deterministic Model	
Concrete Material Dynamic Stochastic Model	
Visual Pictorial Static Model	
Visual Pictorial Dynamic Deterministic Model	
Visual Pictorial Dynamic Stochastic Model	
Gestural Bodily Dynamic Deterministic Model	
Beads	These supplies are craft supplies to be used the station where students make their own model to represent lithography.
Ribbon	
Construction paper	
Glue	
Scissors	
Tape	
Thin bendable wire	
String	
3 models of a molecule	These can be any that you want, but I would encourage some that are on the computer, some that are three-dimensional and some that are photos or pictures.
3 models of quantum dots/ DNA origami/ some nanoscale phenomena	
3 models of DNA	
3 models of the atom over time (i.e. plumb pudding model, solar system model, etc.)	

Pre-Class Preparation

Getting the Materials Ready

- Prepare the models and the stations.



DOING THE LESSON

Opening

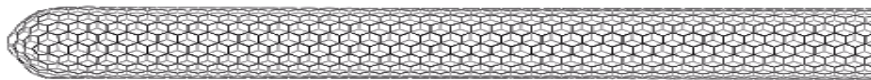
- Students are asked to think about the question, “What are models and why are they useful?” To explore this question, they are assigned to reflect on the questions listed below (pre-activity questions).
- Pre-activity questions for reflection (S= student and teacher questions; T= teacher only questions)
 - (S) What is a model?
 - (S) What are the purposes of models?
 - (S) How are models used in science and engineering?
 - (S) Why are models important for research, investigation, teaching, and learning in the fields of nanoscale science, engineering, and technology?
 - (T) Describe a lesson that you teach that includes a model or models. Why do you use a model or models in this lesson? How do you utilize the model in your instruction?
- (45 minutes) Upon completion of the written reflection, students are asked to share their ideas in a small group. They also are asked to answer the following questions in a small group discussion:
 - What did you learn about your own ideas of models from the reflection and hearing others’ reflections?
 - What kinds of differences did you notice about your ideas on models and someone else’s ideas on models?
 - Did the discussion change the way you thought about the purpose of models?
 - (T) Did the discussion change the way you thought models can or should be used in instruction?

Body

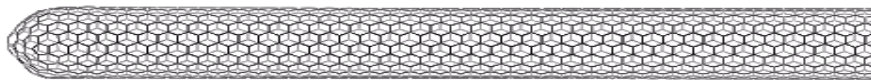
- Students investigate models and their purposes by interacting with models, follow up with a whole class discussion. Teachers continue the exploration of models by reading and discussion some research on student conceptions of models and then create or find a model they can use in a lesson on a nanoscale phenomena that they design.

Activity 1 – Stations (2 hours)

1. Students spend 20 minutes at each station and answer the corresponding questions for that station.
 - a. Model Types Station: Using Boulter & Buckley’s typology as a guide, this station will have models of the following types:
 - i. Concrete Material Static (MODEL), Concrete Material Dynamic Deterministic (MODEL), Concrete Material Dynamic Stochastic, Visual Pictorial Static (MODEL), Visual Pictorial Dynamic Deterministic (MODEL), Visual Pictorial Dynamic Stochastic (MODEL), Gestural Bodily Dynamic Deterministic (MODEL)
 - ii. Questions:
 1. Which of these are models? Explain your rationale for each.
 2. What similarities do these items have?



3. What differences do they have?
4. How would you define a model?
- b. Model Multiplicity Station: This station will include multiple models of the same phenomena:
 - i. In this case, models of a molecule (balloon, ball and stick, computer models, etc.)
 - ii. Questions:
 1. If you were explaining the structure of a molecule to someone else, which model or models would you choose? Why?
- c. Model Critiques and Accuracy Issues Station: This station will include some text about a concept that students should be fairly familiar with and a few models that represent that concept.
 - i. Models of DNA
 - ii. Questions:
 1. Are any of these models completely right? Which one(s)?
 2. What aspects of DNA do each of the models accurately represent? Which aspects are not accurately represented?
 3. Are models useful if they are not completely accurate? Explain your reasoning.
- d. Models as Tools for Investigation Station: This station will have a model or models that allow students to investigate a phenomenon.
 - i. Phase changes (computer simulations) from Molecular Workbench (Concord Consortium website) and Brownian motion simulations from Molecular Workbench.
 - ii. Questions:
 1. Concept questions about phase change based on the model of choice and Brownian motion
 2. What is the value of the model in facilitating understanding of the phenomena of phase changes?
- e. Models as Part of NOS and NOE: This station will have models of a concept as the concept changed over time.
 - i. Models of the atom over time and text describing the evolution of the model
 - ii. Questions:
 1. Is there any value to the previous models made of the atom? Explain your reasoning?
 2. Why do models of the same thing change?
 3. How do models contribute to science and engineering progress?
- f. Designing Models: This station will include a description of a phenomenon that students should be moderately familiar with and include text that describes the phenomena.
 - i. Photolithography text
 - ii. Questions:
 1. Create a model to represent the phenomena discussed in the text.
 2. Was it easy or difficult to design your own model? Why?



3. Did you learn anything from designing your own model?
- g. Models and Nano: This station will have models of nanoscale phenomena.
 - i. Quantum dot models/ DNA origami models/ models of some other nanoscale phenomena
 - ii. Questions:
 1. How do think scientists were able to create these models since none of these objects can be “seen” with a light microscope?
 2. How useful do you think these models are?

Activity 2 – Literature Jigsaw

1. Teachers are divided into groups of three and each member of the group reads a different article.

Coll, R. K., France, B., & Taylor, I. (2005). The role of models/and analogies in science education: Implications from research. *International Journal of Science Education*, 27(2), 183-198.

Harrison, A. G., & Treagust, D. F. (2000). Learning about atoms, molecules, and chemical bonds: A case study of multiple-model use in grade 11 chemistry. *Science Education*, 84(3), 352-381.

Grosslight, L., Unger, C., & Jay, E. (1991). Understanding models and their use in science: Conceptions of middle and high school students and experts. *Journal of Research in Science Teaching*, 28, 799.

2. Teachers jigsaw the articles. To jigsaw, means that each person that read the same article meets for 15 minutes and helps each other make sense of the main points. They then return to their small groups and share the articles with each other.

Activity 3 – Incorporating a Model into a Lesson on a Nanoscale Phenomena

1. Teachers find or create a model that they choose to incorporate into a lesson on a nanoscale phenomena.
2. Teachers describe how they would use the model in the context of your instruction.

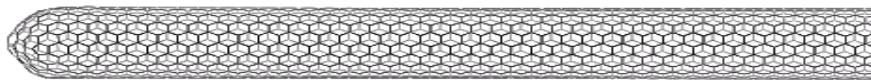
Wrap-up

- Presentation of models and description of use in context of lesson.
- Questions to address:
 - Why are models important to nanoscale science, engineering, and technology?
 - How are they used in the field?

Assessment

- Formative Assessments Table

• Assessments	• Where in lesson	• Possible correct responses
• Station	• Body	• Those that align with the



Questions		learning goals
<ul style="list-style-type: none">Models used in lesson plans	<ul style="list-style-type: none">Follow-up	<ul style="list-style-type: none">Those that incorporate ideas from the learning goals

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RESOURCES

Boulter, C., & Buckley, B. (2000). Constructing a typology of models for science education. In Gilbert & Boulter (2000). Developing models in science education. Dordrecht: Kluwer.

SUPPLEMENTAL MATERIALS

Standards

Indiana State Standards

Grade7

7.1.7 – Explain how engineers, architects, and others who engage in design and technology use scientific knowledge to solve practical problems.

7.7.2 – Use different models to represent the same thing, noting that the kind of model and its complexity should depend on its purpose.

Grade 8

8.1.6 – Identify the constraints that must be taken into account as a new design is developed, such as gravity and the properties of the materials to be used.

8.1.8 – Explain that humans help shape the future by generating knowledge, developing new technologies, and communicating ideas to others.

Benchmarks

11 B 6-8 Models are often used to think about processes that happen too slowly, too quickly, or on too small a scale to observe directly, or that are too vast to be changed deliberately, or that are potentially dangerous.

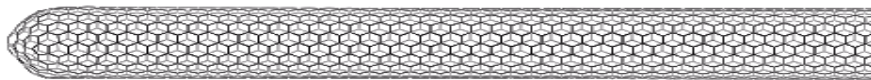
11 B Grades 6-8 Different models can be used to represent the same thing. What kind of a model to use and how complex it should be depends on its purpose. The usefulness of a model may be limited if it is too simple or if it is needlessly complicated. Choosing a useful model is one of the instances in which intuition and creativity come into play in science, mathematics, and engineering.

NSES

Science and technology 5-8

Understanding about science and technology

Science and technology are reciprocal. Science helps drive technology, as it addresses questions that demand more sophisticated instruments and provides principles for better instrumentation and technique. Technology is essential to science, because it provides



instruments and techniques that enable observations of objects and phenomena that are otherwise unobservable due to factors such as quantity, distance, location, size, and speed. Technology also provides tools for investigations, inquiry, and analysis.

Model Typology

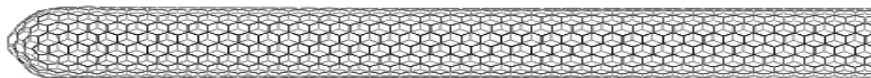
Boulter & Buckley Model Typology (2000)

Modes of Representation

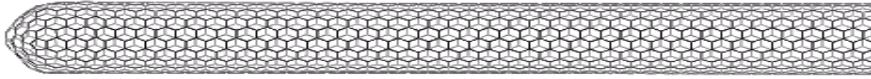
Concrete	3D material models; e.g. a plastic heart
Verbal	Models that are heard or read, of description, explanation, narrative, argument, analogy, and metaphor; e.g. The heart is a pump.
Visual	Models that are seen, such as diagrams, animations, some simulations, video; e.g. circle and line drawing of an eclipse.
Mathematical	Models that are formulae, equations, and some simulations; e.g. equations of planetary motion.
Gestural	Models that are movements of the body or its parts; e.g. a solar system made of pupils moving around each other.

Attributes of Representation

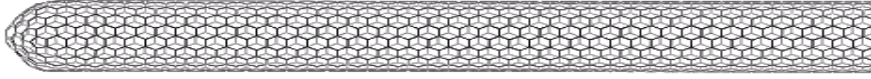
Quantitative versus Qualitative	Is the representation precise as in scale drawings or equations or is it qualitative?
Static versus Dynamic	Is the representation a static one such as a diagram or a dynamic one such as an animation?
Deterministic vs. Stochastic	If the representation is dynamic, is the behavior of the representation always the same (deterministic) or is its behavior based on probabilities (stochastic) and therefore variable?

**Typology Table**

	Static	Dynamic: Deterministic	Dynamic: Stochastic
Concrete Material	3D Model; Scale Models	3D models that move; Working scale replicas	Physical simulations
Visual Pictorial	Diagram; Drawing; Photographs	Sequenced diagrams; Animations; Video of live phenomena	Graphical Displays
Verbal Written/ Oral	Analogy; Description; Metaphor; Description with size or distance		
Mathematical Formulaic	Equations; Chemical formulae	Formulae; Computer simulations	Formulae
Gestural Bodily	Showing Positions; Showing size	Acting out set movements; Gesturing relative behaviors	Hand gestures



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- Describe a lesson that you teach that includes a model or models. Why do you use a model or models in this lesson? How do you utilize the model in your instruction?



Station Questions

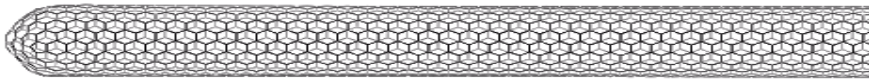
Station 1:

1. Which of these are models? Explain your rationale for each.

2. What similarities do these items have?

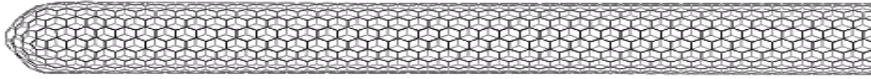
3. What differences do they have?

4. How would you define a model?



Station 2:

1. If you were explaining the structure of a molecule to someone else, which model or models would you choose? Why?

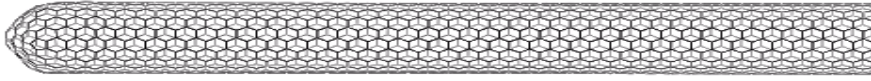


Station 5:

1. Is there any value to the older models made of the atom? Explain your reasoning?

2. Why do models of the same thing change?

3. How do models contribute to science and engineering progress?

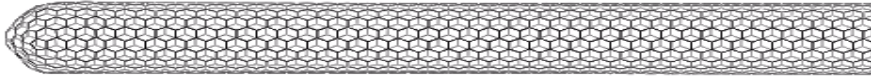


Station 6:

1. Create a model to represent an aspect of nanolithography discussed in the text.
Describe the model you created.

2. Was it easy or difficult to design a model? Why?

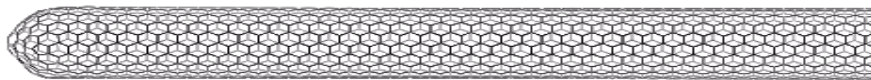
3. Did you learn anything from designing the model?



Station 7:

1. How do think scientists were able to create these models of DNA origami since none of these objects can be “seen” with a light microscope?

2. How useful do you think these models are?



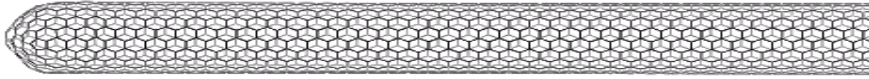
DNA Info Sheet from Wikipedia

DNA. (2008, June 9). In *Wikipedia, The Free Encyclopedia*. Retrieved 16:12, June 10, 2008, from <http://en.wikipedia.org/w/index.php?title=DNA&oldid=218234343>

Deoxyribonucleic acid (DNA) is a nucleic acid that contains the genetic instructions used in the development and functioning of all known living organisms and some viruses. The main role of DNA molecules is the long-term storage of information. DNA is often compared to a set of blueprints or a recipe, since it contains the instructions needed to construct other components of cells, such as proteins and RNA molecules. The DNA segments that carry this genetic information are called genes, but other DNA sequences have structural purposes, or are involved in regulating the use of this genetic information.

Chemically, DNA is a long polymer of simple units called nucleotides, with a backbone made of sugars and phosphate groups joined by ester bonds. Attached to each sugar is one of four types of molecules called bases. It is the sequence of these four bases along the backbone that encodes information. This information is read using the genetic code, which specifies the sequence of the amino acids within proteins. The code is read by copying stretches of DNA into the related nucleic acid RNA, in a process called transcription.

Within cells, DNA is organized into structures called chromosomes. These chromosomes are duplicated before cells divide, in a process called DNA replication. Eukaryotic organisms (animals, plants, and fungi) store their DNA inside the cell nucleus, while in prokaryotes (bacteria and archae) it is found in the cell's cytoplasm. Within the chromosomes, chromatin proteins such as histones compact and organize DNA. These compact structures guide the interactions between DNA and other proteins, helping control which parts of the DNA are transcribed.



Lithography Information

<http://www.webopedia.com/TERM/L/lithography.html>:

The process of imprinting patterns on semiconductor materials to be used as integrated circuits.

http://www.ringsurf.com/online/2015-lithography_e_beam_uv.html:

The field of lithography is vitally important to the electronics industry. It is the only process that can mass-produce microchips and other complex semiconductor devices. Like many other semiconductor processes, it's found a use in making nanostructures out of semiconductor materials.

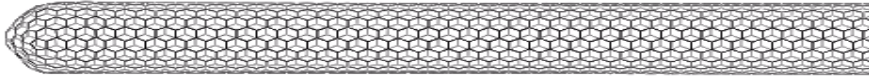
Lithography is actually just one step in the semiconductor fabrication process. However, it is the only step that can effectively guide the other steps that are required. The technique is all about patterning a substrate (or wafer) with a desired layout. To begin, you need to coat the substrate with photoresist. Next, the substrate has to be carefully aligned with its 'mask'. The mask holds the key to the patterning process. By selectively allowing light to pass through, only designated sections of the substrate are exposed. The light will either break down the layer of photoresist or harden it. The portions of photoresist that are weakened as a result can be removed with acid or other volatile substances. Any photoresist that remains will act as a barrier for any subsequent process like epitaxy, doping, or etching. It is with these sequences of photoresist layering, masking, exposure, photoresist removal, and semiconductor processing that makes up the semiconductor fabrication process.

On a given wafer, dozens or hundreds of chips can be made at the same time. The technique is so thoroughly perfected that major chipmakers like Intel and AMD can churn out high-yields at quick speeds.

In nanotechnology, lithography has proven extremely useful in patterning a substrate for selective growth of nanostructures. For instance you can prepare a substrate so that it will grow nanowires and quantum dots in only the selected areas. Lithography can also pave the way for a number of other structures.

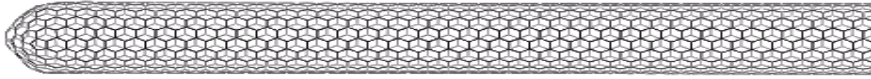
Unfortunately, there are limits to the smallest feature size that is possible with lithography. That's because the light that is used to pass through the mask has a fundamental restriction known as the 'diffraction limit of light'. Many industry experts are worried about this as the demand for faster computer chips grows. Already, modern manufacturers are using high-power lithography to push the limits of the technique. Using extreme ultraviolet rays, it's possible to have feature sizes on the order of 90 nm. While it is possible to create lithographic machines that can go smaller, prohibitive costs are preventing all but the most powerful chipmakers to pursue the research.

Because of this, lithography will never be able to make nanostructures directly. This is also the reason why nanotechnology is so important for the future of electronics. It's one of the only known ways that future miniaturization of electronics can proceed further beyond the fundamental limits of lithography.



<http://nanoatlas.ifs.hr/nano-lithography.html>:

Nano-lithography, a process of making patterns on surfaces with nanometer precision. The basic idea of lithography is very old. However, when one wants to precisely position atoms or molecules on surfaces many problems occur some of which are due to the quantum nature of atoms. There are many techniques presently used which are all termed as lithographies. For example, a tip of the atomic force microscope (AFM) can be used as a 'pen'. The tip is coated with thin film of e.g. thiol molecules (molecules that form self assembled monolayers). During the process of tip movement, the molecules migrate from tip to surface and make a nanoscopic pattern on the surface. This type of lithography is known as dip-pen lithography. Another class of lithographies could be termed as embossing techniques. The idea is to imprint a pattern on the surface using the prepared piece of nanostructured material (stamp) which is pressed against the surface leaving a characteristic pattern behind. These techniques are sometimes used in a combination with UV exposure which stabilizes the pattern. In this case, a thin polymer film is used as a material to be structured. Electron beam lithography uses a scanning electron microscope for writing patterns on surfaces. Due to the electron irradiation, the material locally changes its properties which can then be used to selectively 'etch' the irradiated sample. X-ray lithography functions similarly, only X-ray photons are used instead of electrons. A very interesting type of lithography is called laser focusing lithography or interference lithography. For this technique one creates the standing wave of light above a surface using lasers, thus making a kind of a photolithographic mask. The atoms are evaporated onto the surface, but due to the fact that they interact with light, they are guided by the force-field created by lasers. Thus, the light force field acts effectively as a lens for atoms, guiding them to specific positions and creating patterns on surfaces. This technique can also be combined with the mechanical mask in front of the light force field which additionally directs the atoms to the specific positions. For the best results the atomic beam deposited onto the substrate should be monochromatic (i.e. all atoms should have the same velocity). This poses an important technological difficulty and raises the cost of this technique. The use of nano-lithography is expected to dominate the production of electronic components (chips) structured on a nanometer scale. This could be the way to extend the Moore's law further in the future.



Using Models in a Nano Lesson Plan

In the lesson plan that you develop as a part of this workshop, please include at least one model that you will use in an inquiry or design context. For the models that you choose to use, please reflect on the following questions.

1. What nanoscale phenomena concept are you trying to help convey with your model(s)? What are the key ideas of the concept?
2. Why did you select the specific model(s) you chose for your lesson?
3. Describe how you would use this/ these model(s) in the context of a lesson on nanoscale phenomena.
4. What key concepts from the lesson on models did you consider when deciding what model(s) to use AND how did the models lesson impact how you decided to use the model(s) in the context of your lesson?
5. What role do you think models play in nanoscale science and engineering education?