

Exploring the Structure and Function of the Cell Membrane through a Study of the Modeling Cycle

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Introduction

Models are an essential part of scientific inquiry and science education, from Bohr models in physical science to predator/prey computer simulations in ecology. But for students to recognize the potentials and limitations of scientific models, the modeling process must be explicitly taught in the science classroom. From my experience at Delcastle Technical High School, many students are concrete thinkers and see models as representing real situations, rather than seeing them as rough approximations of a reality and as tools to increase understanding of that reality. The American Association for the Advancement of Science (1990) states that models can mislead students, "suggesting characteristics that are not really shared with what is being modeled."! I have found this to be the case with my students. On the other hand, Al-Balushi (2010) warns that some students (especially tenth graders like the ones I teach), may deny the actual existence of some natural phenomena that we model, due to their abstract nature.' He suggests that this cynicism might be helped by modeling the concept in different ways, by using hands-on experiences, and by discussing the history of the development of the scientific idea.

Through an introduction of modeling in general, a study of physical, geometric, mathematical and computer modeling, and an application of the modeling cycle process in this biology course, students should come to a better understanding of the many uses of modeling in scientific inquiry, as well as a better understanding of the scientific content. While the modeling process can be incorporated into almost any biology unit, I chose the topic of cell membrane structure and function for my curriculum unit. I think this is a natural way to embed and scaffold the learning of models and the modeling process. It can also give students a chance to evaluate the usefulness of models while investigating the biology content.

This curriculum unit uses existing activities on cells and the cell membrane to explicitly teach the modeling cycle and the uses of models in science. By the end of the unit, students should be able to connect scientific models with the concepts they are modeling, evaluate existing models and think of ways to improve them, and answer the overarching question: How does cell structure, including the size and shape of cells, relate to its function of moving materials into and out of the cell?

Student Population and Science Sequence

The New Castle County Vocational Technical School District (NCCVT) consists of four high schools located in New Castle County, Delaware, educating over 4700 students.³ Delcastle Technical High School is a vocational/technical school that includes a diverse population of almost 1500 students. According to 2011-2012 Delaware Department of Education data", 53.3% were low income, 9.6% were in special education, and 3.2% were English language learners. The student body in 2011-2012 was composed of 36% African American, 21.9% Hispanic/Latino, and 41 % Caucasian students, with very few students from other ethnic groups. The students come from many different public middle schools across New Castle County, as well as a few parochial and private schools. They all have different experiences with science education and come to Delcastle at different levels of scientific understanding.

At Delcastle, students take Physical Science their freshman year and Biology their sophomore year. Because of our vocational focus, there is no tracking for science courses, and no Advanced Placement courses for science are available. The most successful students may choose to take a more rigorous sequence, taking Chemistry their junior year and Physics and/or Advanced Biology in their senior year. Other students will take Integrated Science (including concepts from ecology, astronomy, and the fundamental forces of the universe) and may opt to take Environmental Science or no science at all in their senior year.

Because biology is taught to all students in an inclusive setting, there is a wide range of reading and mathematical abilities among our students. Our inclusion classes may include beginning readers and students with significant learning disabilities, as well as those reading above grade level with high scientific aptitudes. This presents a challenge, meeting the needs of all our students while teaching all the essential science concepts required by the Delaware science standards.

Course Scope and Sequence

Last year, Delcastle began using SEPUP Science and Global Issues (SGI) as its biology curriculum.' The three units we use for the biology course focus on cell biology, genetics, and evolution. Unfortunately, SGI is not completely aligned with Delaware Science Content Standards, so we must add activities to fill the gaps. The relationship of cell size and shape to the function of membrane transport is one of these gaps. This topic presents a perfect opportunity to integrate modeling and geometry into the science curriculum.

Although I intend to introduce modeling early in the course, the activities for this unit will take place midway through the cell biology unit. All of the activities focus on cell structure and function, especially that of the cell membrane. Students will have already

learned about cell structures and specialized cells before these activities. The activities in this unit will include two SGI activities that model the cell membrane using bubble solution and then dialysis tubing. These two activities will precede the activities modeling cell size and shape. The unit continues with cellular processes such as photosynthesis and cellular respiration, and ends by investigating the role of enzymes in cellular metabolism.

Student Misconceptions

As discussed before, it is possible for models to create student misconceptions, but that is not the only source of misconceptions when dealing with the cell membrane. One challenge in teaching cell size and shape and their effects on membrane transport is that for many students the concept is counterintuitive. In my experience, most students assume that larger cells are more efficient at diffusing materials because they have more surface area (more membrane) for materials to be transported across. But large cells have a lower surface area to volume ratio. Students do not take into account that the volume of the cell (the cytoplasm) actually increases faster than the surface area when increasing cell size, thus making large cells less efficient. By addressing this concept with different strategies, including visual representations and mathematical calculations, students will hopefully correct their thinking and come to a better understanding of how cell size and shape affects the function of membrane transport.

Modeling in the Science Classroom

Models can help explain phenomena not easily understood by simple observation. Some concepts, such as the structure of the atom, are too small to observe directly, while other concepts, such as photosynthesis, are too complex to easily understand. Some phenomena, such as the interrelationships in an ecosystem, have too many variables to easily understand cause and effect, and sometimes the patterns in the data are too complex to simply display with conventional means. Modeling is a critical part of scientific inquiry, and modeling shares much in common with what science teachers teach as the scientific method. Reese and Campbell (p. 126) describe the discovery of the structure of the cell membrane as one such situation. Scientists used chemical analysis to help create models of the cell membrane, decades before electron microscopy was available to support their ideas. Modeling is similar to other forms of scientific inquiry in several ways. They are creative processes. Models, like other scientific ideas, are based on available evidence and prior knowledge. Models can be tested and have predictive power.

The Common Core State Standards for Mathematics (CCSS-M)7 has placed modeling as a high priority in the curriculum throughout the elementary, middle, and high school

grades. Mathematical modeling is the fourth of eight mathematical practices that should be developed in students throughout their education. Modeling is also one of the six conceptual standards at the high school level, and teachers are encouraged to teach modeling in relation to the other standards: number and quantity, algebra, functions, geometry, and statistics and probability. Modeling involves decision-making throughout the process, including evaluating and revising the model (see Figure 1). According to CCSS-M:

The basic modeling cycle is summarized in the diagram. It involves (1) identifying variables in the situation and selecting those that represent essential features, (2) formulating a model by creating and selecting geometric, graphical, tabular, algebraic, or statistical representations that describe relationships between the variables, (3) analyzing and performing operations on these relationships to draw conclusions, (4) interpreting the results of the mathematics in terms of the original situation, (5) validating the conclusions by comparing them with the situation, and then either improving the model or, if it is acceptable, (6) reporting on the conclusions and the reasoning behind them. Choices, assumptions, and approximations are present throughout this cycle. (p. 72-73)

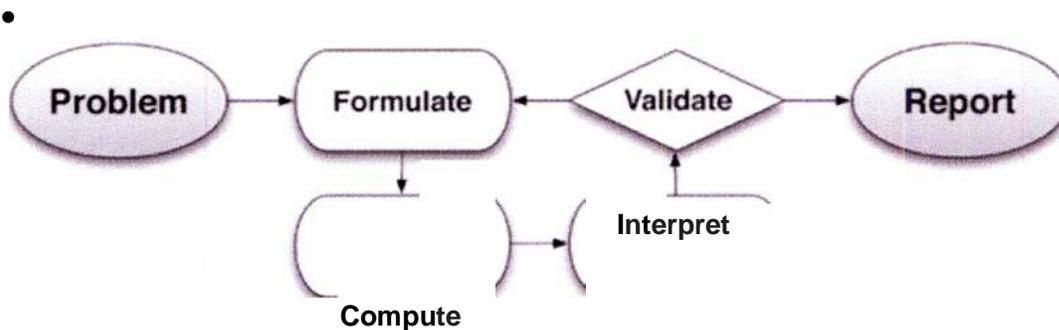


Figure 1. One version of the modeling cycle (CCSS-M, p. 72)

The CCSS-M diagram above is not the only way of representing the modeling cycle. The modeling cycle I use in this curriculum unit is one similar to the one used in our Delaware Teachers Institute seminar, "Modeling with Mathematics." (See Figure 2.) I prefer to use this diagram in representing the modeling cycle, as it includes the predictive power of models (something that is of great importance in scientific inquiry). In applying this modeling cycle to scientific inquiry, the system or reality is the scientific content (for example, the cell membrane). Once the problem or question has been established ("What is effect of solute concentration on the rate of osmosis?"), choices must be made as to what variables are essential in formulating the model. If a mathematical model such as an equation is formulated, then that model can be analyzed according to current theory and then used to predict behavior in other situations. That prediction could be tested and compared to the results, and the model can be improved and/or new questions developed.

The Modeling Cycle

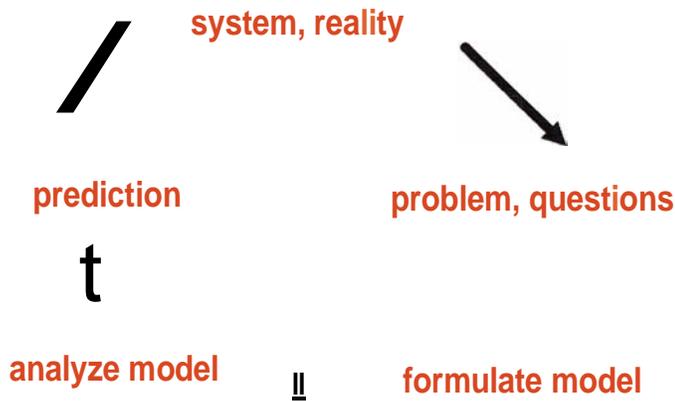


Figure 2. Another version of the modeling cycle, based on one used in the DTI seminar, "Modeling with Mathematics"

Content

Why are cells so small? Although an elephant is much larger than a mouse, it doesn't have larger cells; it just has more of them. The maximum size for the typical, roughly spherical cell is approximately 100 micrometers.⁸ Organisms larger than that are multicellular. The reason cells are so small has to do with diffusion rates. Cells must transport materials such as nutrients and waste across the cell membrane and throughout the cell. The distance these materials must travel becomes too great when the volume of the cell is large. Because all materials must cross the cell membrane, the determining factor of size is the surface area to volume ratio.

Because cells come in all shapes and sizes, determining the surface area of actual cells is problematic. Although most cells are not spherical or cubic in shape, using a sphere or a cube as a model of a cell makes it much easier to look at the relationship between the size of a cell and its surface area to volume ratio. The surface area of the geometric solid represents the cell membrane, while the volume of the solid represents the cytoplasm.

- For a cube, $SA = 6a^2$ and $V = a^3$, where SA is surface area, V is volume, and a is the length of one side.

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For a sphere, $SA = 4\pi r^2$ and $V = \frac{4}{3}\pi r^3$, where r is the radius.

The cell membrane is made up primarily of phospholipid molecules, arranged in a bilayer. The heads of phospholipids are polar, making them hydrophilic (water-loving), while the two fatty acid tails of the molecule are non-polar and thus hydrophobic (water-fearing). Because a watery environment exists both inside and outside the cell, the phospholipids are arranged in two layers, with the hydrophobic tails facing inward toward each other and the heads facing out. Materials that diffuse passively across the membrane, from high to low concentration, include gases such as oxygen and carbon dioxide. Other materials, such as glucose, are unable to cross the phospholipid bilayer freely and must be transported using proteins that traverse the cell membrane. This is known as facilitated diffusion. Both types of diffusion occur without the input of energy. Glucose can also be transported against the concentration gradient, from low to high concentration, using active transport. As its name implies, active transport requires an input of energy, either from chemical energy in molecules such as adenosine triphosphate (ATP) or by an electrochemical gradient, as in the case of glucose.

Implementing National, State and District Standards

This curriculum unit, developed for an inclusion Biology course at Delcastle, focuses on the following essential understanding included in the current Delaware Science Content Standard 6 (Life Processes): "Living systems, from the organismic to the cellular level, demonstrate the complementary nature of structure and function.,,9 This includes relating the varied forms of cells in different organisms to their functions, and relating the dynamic structure of the cell membrane to its function of transporting materials into and out of the cell. One of the grade level expectations for this standard is to construct cell models to relate cell size and surface area to volume ratio to diffusion rates, explaining why cells are small.

This curriculum unit has also been developed with the Next Generation Science Standards, the Common Core State Standards, and a STEM (science, technology, engineering and mathematics) approach in mind. The intent is to teach this unit with an emphasis on the core idea of structures and processes in life science, the broad crosscutting concept of structure and function (HS- LS I-a), and the science and engineering practice of developing and using models (HS- LS I-g) as suggested by the Next Generation Science Standards. ¹⁰ Less emphasis is placed on memorizing specific cell types and how their structures relate to their functions. Instead, students investigate cell size and shape and relate this to the structure and functions of different cells. They are asked to apply their knowledge to new, but related situations as an assessment.

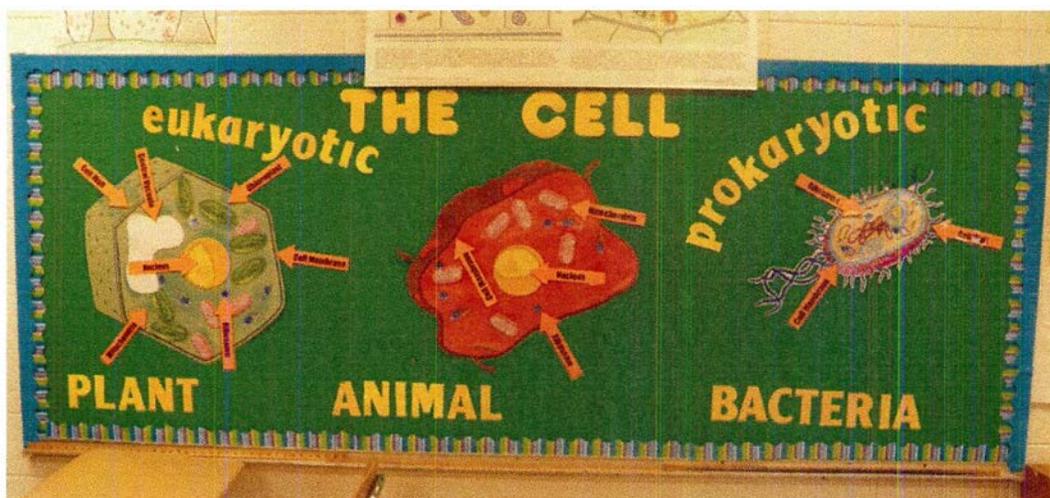
Finally, in addition to the modeling component of CCSS-M, the following High School Geometry standards will be used: geometric measurement and dimension (including surface area/volume formulas and visualizing two-dimensional and three-dimensional objects) and applying geometric concepts in modeling situations.

• Classroom Activities

The beginning of the SGr Cell Biology unit applies the concept of the cell to human diseases, making it relevant to the students' lives. The first activity looks at how sustainability of a community is related to the health of its individuals. The second has students collect data from blood samples and health histories of hypothetical patients, determining what diagnoses are probable while introducing the concept of the cell. The next few activities investigate cells of both unicellular and multicellular organisms, using prepared slides and live organisms, computer simulations and interactive tutorials, and text.

Activity 1: The Cell Wall

I have one wall of my classroom designated as the cell wall for the entirety of the course (see Figure 3). This wall is divided into three sections: two for eukaryotic cell types (plant and animal) and one for prokaryotic (typical bacterial cell). Because our standards concentrate on cell structure and function in general, and not on memorizing all the organelles and their functions, I only include cell structures (with labels) that will be discussed most often in the course: cell membrane, cytoplasm, cell wall, nucleus, ribosomes, chloroplasts, and mitochondria. At the beginning of the course, there are three



empty "cells" with only the following labels: animal, plant, bacteria, eukaryotic, and prokaryotic. After viewing prepared slides of prokaryotic (bacteria of different shapes, such as *E. coli*, *Staphylococcus*, and *Borellia*), and eukaryotic cells (such as *Elodea* leaf, onion epidermis, and human cheek cells), students complete a computer activity developed by SGr that compares plant and animal cells. After reading about bacterial cells in the SGr textbook, I distribute the various cell structures and labels to the students

(each student receives two to three items). I then lead them through a discussion of the cell structures, having students add their items to the cell wall as we discuss them. After the cell wall is complete, I do a think-pair-share to have students compare and contrast the model cells with the cells they viewed under the microscope:

- Think: "Think to yourself, how are the cells on the cell wall similar to those you viewed under the microscope? How are they different? Write your ideas in your science notebook."
- Pair: "Turn to your shoulder partner and share your ideas. Add any new ideas to your science notebook."
- Share: Lead students in a discussion to share their ideas.

Most students realize that the real cells look very different from the cell wall. I then introduce the concept of a model, and ask questions such as:

- Are cells flat like what we see on the cell wall?
- Are mitochondria really red and ribosomes really purple?
- Why do you think scientists make models of things like cells?

I then show them a three-dimensional plant cell model and ask whether or not they think this is a better representation of what a cell is, having them justify their answers with specific examples.

This is the students' first formal introduction to the concept of a model, so we discuss how models such as these physical models are useful in science. I introduce the simplified modeling cycle based on the one given to us in our seminar (see Figure 2 above), explaining each component of the cycle. I then have them relate each component to our cell wall model. For example, they should identify the "system/reality" as the structures of the cell, and analyze the model by asking "What information can the model give us?" I purposely omit the prediction portion of the model at this time, completing the cycle by having the students compare the cell model to the actual cells they viewed under the microscope. As a formative assessment, I have the students write the strengths and weakness of our cell wall model, explain why we use this cell wall to help learn about cells, and imagine how this model might help predict something about cells.

Activity 2: A Model Membrane

The first activity that addresses the cell membrane itself is SGI Cell Biology Activity 7: A Model Membrane. Students use bubble solution, bubble wands made of straws, and several tasks to model different properties of the cell membrane, such as flexibility,

fluidity, selective permeability, the ability to repair itself, and the presence of transport proteins that assist in membrane transport. These tasks include:

- bending the wand and observing the bubble film
- passing a dry toothpick or a plastic cylinder through the bubble film
- coating the cylinder in bubble solution to allow the dry toothpick to pass through without popping
- laying a dental floss "lasso" on the bubble, popping the interior of the lasso, and then pulling out the lasso so that the hole reforms.

I show the modeling cycle figure, and after having students identify first four parts of the modeling cycle, have students brainstorm the ways that this physical model might have predictive value. They should determine that this model could predict what would be necessary for materials to pass the cell membrane without popping it - the transported material must be similar in properties to the membrane itself if it is to cross the cell membrane, such as when the plastic cylinder coated in bubble solution passed through the bubble. It could also give some insight into how a cell membrane might repair itself - like the bubble solution spread out to repair the hole in the lasso, the phospholipids could move around to repair a hole in the cell membrane. I then revisit the "system/reality" part of the cycle, and have students suggest ways this model could be improved.

Activity 3: Modeling the Bilayer

In this activity students use paper phospholipids, water molecules, and proteins to assemble a cell membrane. The easiest way is to have an 8.5" x 11" sheet of paper displaying water molecules on each side, with space in the middle where they will build their membrane. (A sample template and phospholipids are provided in the Appendix.) Before an in-depth discussion of the structure of the cell membrane, I tell the students that the cell membrane is made up of phospholipids, with other molecules embedded in or attached to the cell membrane. I purposely avoid a discussion of the bilayer, but I do describe the structure of a phospholipid and review the concepts of polarity and hydrogen bonding they learned previously in Physical Science. Students work in pairs to predict the structure of the cell membrane. Students should determine that because both the internal and external environments of the cell are watery, the hydrophilic heads of the phospholipids face those areas, while the hydrophobic tails face away from the water. Very few of my students quickly form a bilayer. Most will have some part of the hydrophobic fatty acid tails touching water, so as I circulate around the room I point this out and ask them to revise their structure. After some manipulation of the phospholipids almost all students correctly form a bilayer (see Figure 4), and I project an image of an electron micrograph of the cell membrane to have them compare their model to the actual image. This has taken them a step further in the modeling process; they are now using models and their knowledge of chemistry to predict the structure of the cell membrane.

They are also comparing their models to an electron micrograph of an actual membrane. By the end of the activity, students should be able to see the predictive power of these two-dimensional phospholipid models, in that they were able to model the bilayer, based on the structure and properties of the phospholipids themselves.

The addition of proteins embedded in the cell membrane could be used in the same way. Students could be given model proteins with some information about their properties and be asked to add them to their model. They should connect this to what they did in Activity 2 when they coated the plastic cylinder in bubble solution to allow the toothpick to cross the bubble membrane.

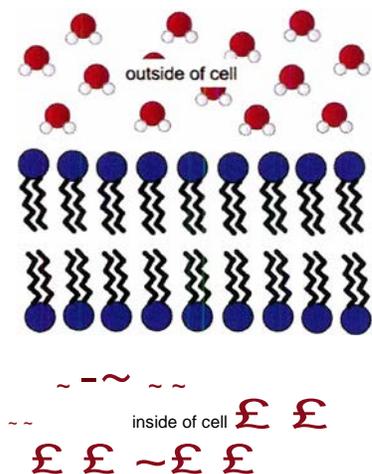


Figure 4. Sample model of the phospholipid bilayer

Activity 4: Modeling Diffusion Across a Membrane

The next activity is an adaptation of SGr Cell Biology Activity 8 that models the functioning of the cell membrane, using dialysis tubing and different solutions. Students first make a model of the cell membrane by wetting 10 em pieces of dialysis tubing, opening the tubing, and tying a knot in the very bottom. Equal amounts of glucose solution (about 20%) and starch solution are added to the model cell. The tubing is then placed in a beaker of water for 20 minutes, and the solution in the beaker is tested for the presence of starch (using iodine solution) or glucose (using Benedict's solution). Students find that glucose can cross the membrane, but starch cannot. They then add a few drops of iodine solution to the beaker, and wait to see if iodine can diffuse across the tubing (which it quickly does). Through this activity students come to an understanding that the cell membrane is permeable to some substances but not others.

Students should again relate this activity to the different steps of the modeling cycle, analyzing the strengths and weaknesses of this particular model when compared to the other model. They should realize that different types of models serve different purposes, as this model provides information about the function of the membrane while the other models illustrated the structure of the membrane.

The second part of this activity introduces mathematical modeling to the modeling process. Students again make a model of the cell membrane with dialysis tubing as described above. They then fill the tubing with a few milliliters of 20% sucrose solution. A second knot is tied at the top of the tubing, leaving room between the top knot and the solution. This is repeated four times, for a total of five "cells." The tubing is dried off and the mass in grams is determined and recorded for each "cell." They are each placed in a beaker containing a different concentration of sucrose solution: 0% (pure water), 10%, 20%, 30% and 40%. (It's difficult to get the sucrose to dissolve at such a high concentration, even with heating, so 40% is as high as I go.) After allowing them to remain in the beakers for 20 minutes, the "cells" are dried and the mass is determined and recorded again. The difference in mass is calculated for each condition, and the difference is graphed against the solution concentration outside the tubing. Students use graphing calculators or Microsoft Excel to graph the data, and regression analysis is used to determine an equation that models this relationship. Students interpret their results, determining what is crossing the membrane, and why. (The concentration gradient causes water to move from the hypotonic to hypertonic sides of the membrane, because sucrose cannot cross the membrane - it is too large a molecule.) Students can then use their model equations to predict what would happen to their model cells at different concentrations of sucrose solution, and use this information to predict what might happen to real blood cells if a patient is given an IV that is either hypotonic or hypertonic to the cell.

Once again, students should connect this activity to the modeling cycle, this time focusing on the ability of mathematical models to make predictions that the prior models were unable to do.

Activity 5: Cell Size and Surface to Volume Ratio: A Differentiated Activity

Because there is no tracking for the biology course at Delcastle, there is a wide range of scientific background as well as reading and math abilities in the classroom. Students range from SRI scores of BR (beginning reader) to scores beyond 1400. A similar range can be observed with math scores and science scores according to DCAS (Delaware Comprehensive Assessment System). Differentiation becomes imperative for every student to come to an understanding of scientific concepts. In the next activities, students are assigned different tasks depending on their ability levels. All the groups communicate their findings to the rest of the class, and the students evaluate the effectiveness of each

model. All of these activities could be used sequentially for all students, if time allows, but I feel it is the best use of our class time to use these activities to differentiate learning.

For each activity, students are asked to connect their models to the each part of the modeling cycle. They should answer questions such as:

- How is the cell being modeled?
- What information does this model tell you about the cell?
- What predictions can you make based on this model?
- What are the strengths and weaknesses of this model?
- How could the model be improved?

Remedial Activity: How does cell size affect diffusion rates? Students use agar blocks to study diffusion rates of different sizes of cells, and then apply mathematical formulas to connect the visual representation and diffusion rates to the ratio of surface area to volume. Students then relate these models to specialized cell types, reflect on their geometric models, and assess their approximation to these different cell types.

Materials needed (per pair of students):

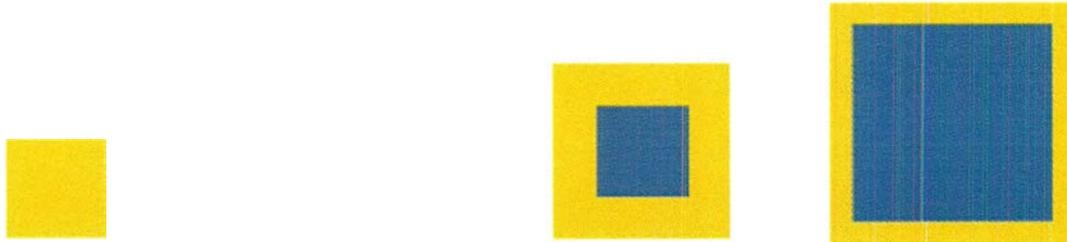
- plastic knife and spoon
- clear metric rulers
- block of 2% agar with bromthymol blue (BTB), approximately 6cm x 6cm
- 100 mL beaker with enough vinegar to cover blocks (I reuse the vinegar throughout the day.)
- paper towels

In preparation for this activity, I make enough agar for students to make blocks in pairs. There are many different recipes online, including ones that use phenolphthalein agar blocks (that students soak in sodium hydroxide). See Appendix for recipe.

Before beginning the activity, I explain to the students how BTB changes color from blue to yellow in the presence of acid, like vinegar. Students carefully cut cubes out of the agar - ideally 3 cm, 2 cm, and 1 cm. (Students often have trouble making precise cubes, but as long as they are close, the demonstration will be successful.) They use the spoon to place the cubes in the vinegar until the smallest cube has turned yellow (about 5 minutes), then remove and rinse all three blocks, cut them in half, and using colored pencils, draw what they observe.

After they have drawn their results, they calculate the surface area and volume of each cube, assuming their measurements are precise. They then compute the surface area to volume ratio for each, writing their calculations below their drawings (see Figure 5 below). I have them circle the drawing where the vinegar completely diffused throughout the agar block (the smallest one), and ask whether the surface area to volume ratio was

the smallest or the largest in this case. Students should come to the conclusion that not only does the smallest cell have the most surface area when compared to volume, it is also the most efficient at diffusing materials throughout the entire cell.



"Cell" Dimensions	1 em x 1 em x 1 ern	2 em x 2 ern x 2 em	3 em x 3 em x 3 em
Surface Area (SA)	6 em"	24 ern"	54 ern"
Volume (V)	1 cnr'	8 crrr'	27 cm '
SAN	6 ern"	3 ern"	2 em"

Figure 5. Sample results of agar block activity

I then students ifthis model allows them to predict how quickly vinegar might diffuse in cells of different shapes and sizes. As an example, ask them to predict what they expect would happen if they had an agar cube with dimensions 3 em x 3 em x 1 em. They should predict that it would diffuse completely in less time than both the 3 em and 2 em cubes but take more time than the 1 em cube. If time allows, I have them test their predictions by timing how long it takes the vinegar to diffuse completely in the different blocks.

Basic: How does cell size and shape affect diffusion rates? To make the above activity more challenging, students can then calculate diffusion rate by timing how long it takes for the vinegar to diffuse throughout the block (remind students that the rate should be based on 0.5 em since that's the distance to the center of the block). They then calculate the unchanged volume of the remaining blocks, subtract that from the total volume to find the amount of diffused volume, and then plot length of side of cube against the percent of the total volume that was diffused.

These students can also investigate the effect of shape on the surface area to volume ratio, and thus diffusion rates. Students use centimeter blocks to build and calculate surface area and volume of different shapes and sizes of model cells. I usually keep the volume the same, using the following dimensions: 3x3x2, 9x2x1, and 18x1x1. In this way students can easily see how shape affects the surface area of the cell, and observe how flattening and lengthening increases the surface to volume ratio.

Advanced: Students use a computer activity by The McGraw-Hill Companies (Johnson Explorations) on cell size and diffusion rates (<http://www.mhhe.com/biosci/genbio/biolink/jexplorations/ch02expl.htm>). Students relate these models to specialized cell types and analyze the usefulness of this type of computer modeling program (see Figure 6).

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Cell Size

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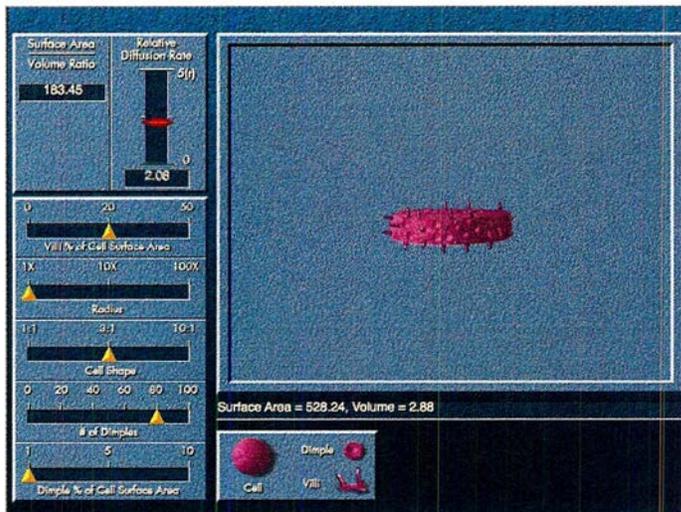


Figure 6. Screen shot of Johnson Exploration cell size computer activity

Students first do one (or both) of the above activities to fully understand what is meant by the concept of surface area to volume ratio. They then go to the Johnson Exploration on cell size and read "How to Use This Exploration" before proceeding with the activity. The program allows students to change five features of the model cell: amount of villi on cell surface, cell radius, cell shape, number of dimples, and percentage of surface area and dimple covers. The simulation calculates the surface area to volume ratio and the relative diffusion rate of each modified cell. Students should first investigate individual features and observe how changing each of these affects both the surface area to volume ratio and the relative diffusion rate. They should then create a table to record their data and graph their data for each feature. Using graphing calculators or Microsoft Excel, they should attempt to express each feature's effect on surface area to volume ratio as an equation. (Because the interactive only allows three to six different levels for each feature, the regression will not be entirely accurate.)

Assessment

Students should be assessed in two main areas: their understanding of models and the modeling process, and their understanding of how the structure of the cell membrane (including cell size and shape) relates to its function. Each group should report to the class the results of their investigations, including the steps of the modeling process as it applied to their models, and a thoughtful evaluation of their models. Students should also be able to apply the concept of increasing surface area relative to volume to new situations, such as other biological structures (e.g. microvilli in the small intestines) and non-biological structures (e.g. shape of a building and its efficiency in heating and cooling).

Appendix

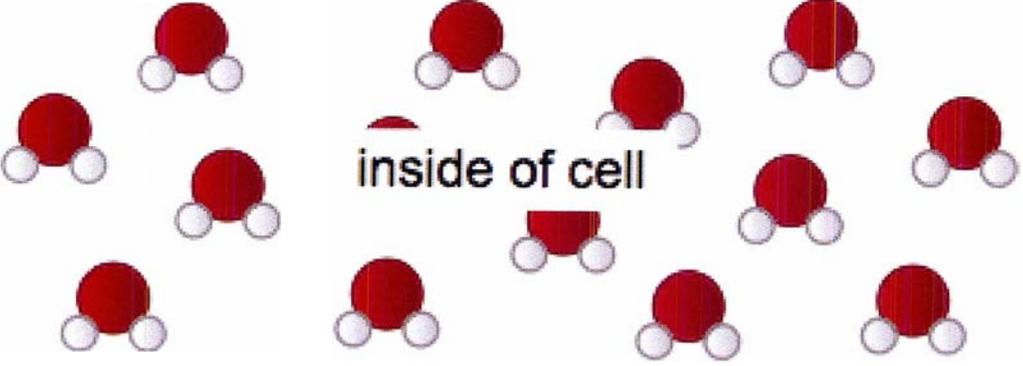
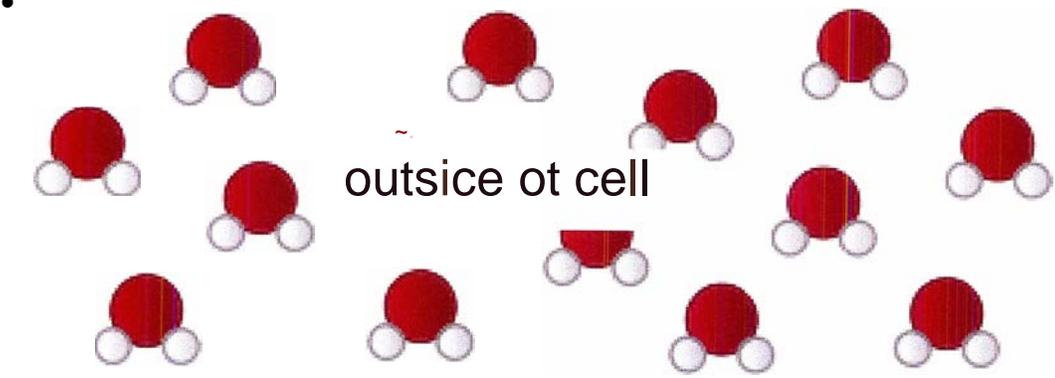
Bromthymol Blue Agar Blocks Recipe

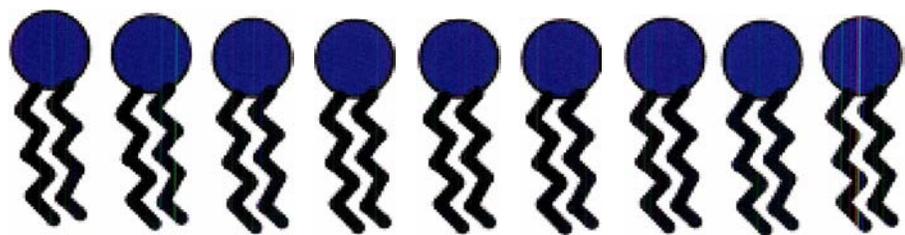
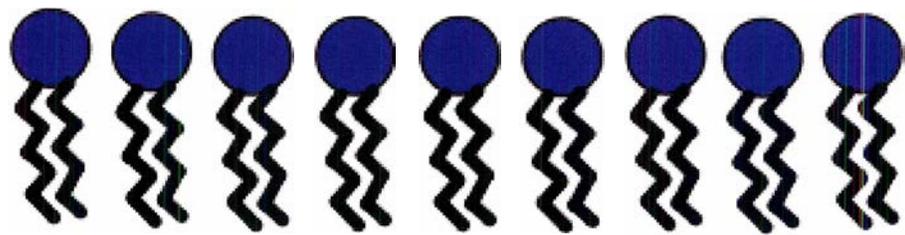
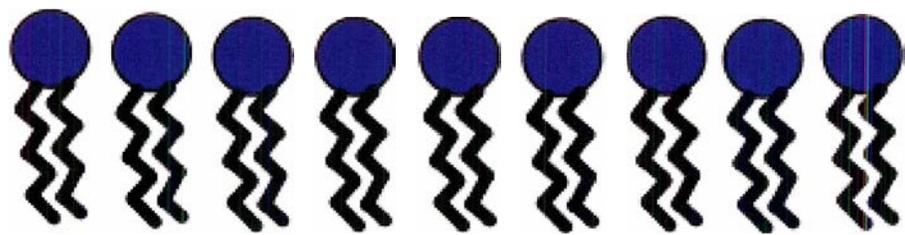
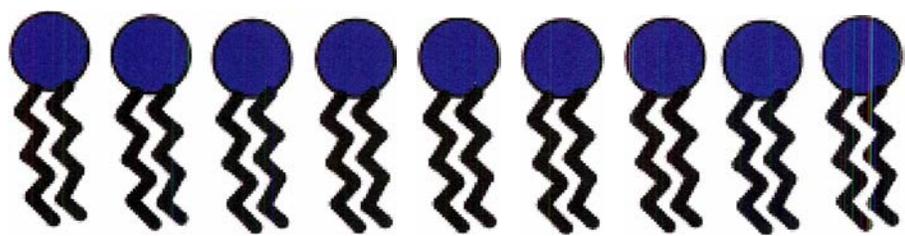
I prefer to make enough agar for students to work in pairs. Each 9"x13" pan provides enough agar for 20-24 pairs of students. It's probably enough for more, but I like to have extra in case students mess up.

Bring 2 liters of distilled water almost to boiling on a magnetic stirring hot plate. (I prefer to have two flasks, each with one liter of water, to make it easier to pour.) Drop in magnetic stirrers and then add 40 grams of agar (20 grams to each flask) and stir constantly until agar is completely dissolved. Pour into 9" x 13" baking pans (2 liters per pan), and then mix in 0.04% bromthymol blue to each until the color is blue-green in color (about 30 mL). Let cool to room temperature, cover with plastic wrap, and refrigerate. This can be made a few days ahead of time, if needed.

Templates for Activity 3: Modeling the Bilayer

Print out the following on standard sheets of paper. Cut out individual phospholipids before giving to the students. I have both the water environment page and the phospholipids laminated to make them more durable.





Notes

1 AAAS. *Science for All Americans*. Publication. New York: Oxford University Press, 1990. <http://www.project2061.org/publications/sfaalonlineintro.htm>.

2 Al-Balushi, Sulaiman. "Students' Evaluation of the Credibility of Scientific Models That Represent Natural Entities and Phenomena." *International Journal of Science and Mathematics Education* 9, no. 3 (June 2011): 571-601. doi:10.1007/s10763-010-9209-4.

3 "School Profiles: NCC Votech District." State of Delaware. Accessed November 11, 2012. <http://profiles.doe.k12.de.us/SchoolProfiles/DistrictDefault.aspx?checkSchool=O>.

4 "School Profiles: Delcastle Technical High School." State of Delaware. Accessed November 11, 2012. <http://profiles.doe.k12.de.us/SchoolProfiles/SchoolDefault.aspx?checkSchool=80>.

5 *SEPUP Science & Global Issues: Biology*. Rondonkoma, NY: Lab-aids, 2010.

6 Reece, Jane B., and Neil A. Campbell. "Membrane Structure and Function." In *Campbell Biology*, 125-41. Boston: Benjamin Cummings, 2011.

7 National Governors Association Center for Best Practices, Council of Chief State School Officers. "Common Core State Standards for Mathematics." Common Core State Standards Initiative. 2010. Accessed November 12, 2012. <http://www.corestandards.org/the-standards>,

8 Reece, Jane B., and Neil A. Campbell. "Membrane Structure and Function." In *Campbell Biology*, 125-41. Boston: Benjamin Cummings, 2011.

9 "Delaware Content Standards for Science." State of Delaware: Department of Education. Accessed November 28, 2012. http://www.doe.k12.de.us/infosuites/staff/cil/content_areas/science.shtml.

10 National Research Council. *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. Washington, D.C.: National Academies Press, 2012.

Resources

The following includes a list of resources for classroom activities and background content information to help facilitate teaching this unit and provide additional ideas for incorporating mathematical modeling into the biology classroom.

Classroom Activities

Beals, M., L. Gross, and S. Harrell. "Diffusion Through a Cell Membrane." Diffusion Through a Cell Membrane. 1999. Accessed November 28, 2012.
<http://www.tiem.utk.edu/~gross/bioed/webmodules/diffusion.htm>.
More advanced activity that applies mathematical reasoning and Fick's law to study both simple and facilitated diffusion.

"Cell Size and Division or How Big Would You Want To Be If You Were A Cell." Cell Size and Division or How Big Would You Want To Be If You Were A Cell. Accessed September 09, 2012. <http://mypages.iit.edu/~smile/bi9226.html>.
This activity uses agar blocks to demonstrate the relationship between cell size and diffusion rates, using phenolphthalein as the indicator and sodium hydroxide as the solution instead of bromthymol blue and vinegar.

"Cell Size Database." Cell Size Database. Accessed November 11, 2012.
<http://www.genomesize.com/cellsize>.
This database contains information about the size of erythrocytes (red blood cells) of all the vertebrate groups. Data could be modeled and analyzed for an additional activity.

Deaver, James. "Modeling Limits to Cell Size." Access Excellence. 1996. Accessed September 9, 2012.
http://www.accessexcellence.org/AE/AEC/AEFI1996/deaver_cell.php.
Students make model cells out of paper and **fill** them with sand to demonstrate surface area and volume of various sizes of cells.

"Estimating Maximum Cell Size." Space Math at NASA. Accessed September 9, 2012.
<http://spacemath.gsfc.nasa.gov/weekly/AstroI4.pdf>.
Worksheet with good math application problems regarding cell size. Includes answer key.

Fick's Law and the Problem of the Apple. University of Toronto. Accessed November 11, 2012. www.erin.utoronto.ca/~w3bio/bi0204/lab_files/ficks_law.pdf.
Good description of Fick's Law and an advanced activity using mathematical formulas to apply Fick's Law to diffusion rates.

Ludwig, Kelly. "Movement Across the Membrane (Diffusion)." Movement Across the Membrane (Diffusion). Accessed September 9, 2012.

<http://mypages.iit.edu/~smilelbi9508.html>.

This contains several simple activities to demonstrate diffusion and movement across membranes.

Computer Activities, Animations, and Tutorials

"Cell Size and Scale." Learn.Genetics. Accessed November 25, 2012.

<http://learn.genetics.utah.edu/content/begin/cells/scale/>.

This interactive demonstrates the relative size of various small objects, from a coffee bean to a carbon atom. Great for visual learners to grasp the idea of scale.

"How Big Is a ... ?" Cells Alive! Accessed September 9, 2012.

<http://www.cellsalive.com/howbig.htm>.

This interactive visualizes relative sizes of microorganisms sitting on the head of a pin.

McGraw Hill Companies. "Cell Size." Johnson Explorations. Accessed November 11,

20 12. <http://www.mhhe.com/biosci/genbiolbiolinkilexplorations/ch02expl.htm>.

This computer model allows students to modify the shape, size and surface landscape of a cell to determine surface area to volume ratios and relative diffusion rates.

"Studying Cells Tutorial." The Biology Project. Accessed January 06, 2013.

http://www.biology.arizona.edu/cell_bio/tutorials/cells/cells.html.

This brief tutorial discusses the relative sizes of cells and their components, and introduces the student to light and electron microscopes as they pertain to visualizing cells.

Viau, Elizabeth A. "Lesson 4 Limits to Cell Size." World Builders. Accessed September

9, 2012. d-builders.org/lessons/lesson4/cellsize.html.

This tutorial introduces how cell size and shape relate to diffusion rates.

Modeling Content Information

Abrams, Joshua P. "Teaching Mathematical Modeling and the Skills of Representation. "

Edited by Albert Cuoco and Frances R. Curcio. In *The Roles of Representation in School Mathematics*, 269-82. Reston, VA: National Council of Teachers of Mathematics, 2001.

This chapter discusses the modeling cycle in depth, and provides information on teaching the modeling process in math curriculum.

Louca, Loucas T., and Zacharias C. Zacharia. "Modeling-based Learning in Science Education: Cognitive, Metacognitive, Social, Material and Epistemological Contributions." *Educational Review* 64, no. 4 (2012): 471-92.

This article reviews Modeling-based Learning, focusing on the contributions that it has made in science education.

Windschitl, Mark, Jessica Thompson, and Melissa Braaten. "Beyond the Scientific Method: Model-based Inquiry as a New Paradigm of Preference for School Science Investigations." *Science Education* 92, no. 5 (January 4,2008): 941-67.

doi: 10.1 002/sce.20259.

This article critiques the scientific method as traditionally taught in schools, and proposes an alternative way of teaching science - model-based inquiry.

Zeeman, Mary Lou. "Mathematical Modeling in Biology." Lecture, Inaugural Lecture: R. Wells Johnson Professorship of Mathematics, Bowdoin College, Brunswick, ME, November 28, 2007. <http://www.bowdoin.edu/podcasts/video/communications/marylou-zeeman-lecture.mov>.

Discusses the importance of mathematical modeling in the biological sciences, using examples from predator/prey relationships and competition among species.

Biology Content Information

Thompson, D'Arcy Wentworth, and John Tyler. Bonner. *On Growth and Form*. Cambridge: Cambridge University Press, 1992.

A fascinating book about the structure and function of living things, full of examples from nature, including a chapter on size and another on cell structures.

Reece, Jane B., and Neil A. Campbell. "Membrane Structure and Function." In *Campbell Biology*, 125-41. Boston: Benjamin Cummings, 2011.

Good reference for membrane structure and function.

Curriculum Unit Title

Teaching the Modeling Cycle While Investigating the Relationship of Cell Structure and Function

Author

Elizabeth Nowak

KEY LEARNING, ENDURING UNDERSTANDING, ETC.

Living systems, from the organismic to the cellular level, demonstrate the complementary nature of structure and function.

Scientists use models to help in their investigation and understanding of complex biological structures and processes. Models are also used to make predictions, and are revised depending on their usefulness and connection to the actual structures or processes under study.

ESSENTIAL QUESTION(S) for the UNIT

How do the structure of cells, including cell size and shape, relate to their various functions?

How are models used in scientific inquiry?

CONCEPT A

Modeling cycle

CONCEPT B

Cell structure and function

CONCEPT C

The relationship of cell size and shape to diffusion rate

ESSENTIAL QUESTIONS A

How is the modeling cycle used in scientific inquiry?

How can models be analyzed for their usefulness?

ESSENTIAL QUESTIONS B

How do the structures of cells relate to their various functions?

How does the structure of the cell membrane relate to its function of transporting materials into and out of the cell?

ESSENTIAL QUESTIONS C

How does the size of a cell affect the rate of diffusion into and out of the cell? How does the shape of a cell affect the rate of diffusion into and out of the cell?

Why are cells small?

VOCABULARY A

model, cycle, scientific inquiry, formulate, analyze, predict

VOCABULARY B

phospholipid, bilayer, hydrophobic, hydrophilic, passive transport, active transport, diffusion, osmosis

VOCABULARY C

surface area to volume ratio, diffusion rates

ADDITIONAL INFORMATION/MATERIAL/TEXT/FILM/RESOURCES

Models: cell wall parts and labels, 3-D cell model and cell membrane model, phospholipids and external/internal cell environment, dialysis tubing, BTB agar, McGraw Hill Johnson Explorations (cell size) and laptops

Microscopes and prepared slides of cells, as well as blank slides, coverslips, *Elodea*, onion; vinegar, 100 mL beakers, plastic spoon, knife, and ruler for agar model activity; various glucose solutions, sucrose solution, iodine solution, starch solution, beakers, for dialysis tubing activity