Modeling Microbes to Scale

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Authors

Thomas Terry
University of Connecticut
Storrs, Connecticut 06269
USA
Email: thomas.terry@uconn.edu

Linda Sherwood
Montana State University
Bozeman, Montana
USA
Email: umbls@msu.oscs.montana.edu

Jillaine Hadfield
University of Maryland
Baltimore, Maryland
USA
Email: jill@medresch.umaryland.edu

Susan Deines
Colorado State University
Fort Collins, Colorado
USA
Email: Susan.Deines@colostate.edu

Marianne Crocker
Ozark Technical Community College
Springfield, Missouri
USA
Email: buglady@ix.netcom.com

Abstract

Students will construct and display models of microbes including viruses, bacteria, and unicellular eukaryotes using a single common scale to demonstrate the diversity of sizes. Viruses may also be modeled at a larger scale to demonstrate greater structural details. This project can be expanded by requiring students to provide written or oral summaries, develop posters, model the length of nucleic acid, and other variations. This activity was designed to improve student understanding of the relative sizes, shapes, and structures found in microbes ranging from viruses to small fungi and protists, and to encourage use of metric units such as nanometers and micrometers.

Activity

Invitation for User Feedback. If you have used the activity and would like to provide feedback, please send an e-mail to MicrobeLibrary@asmusa.org. Feedback can include ideas which complement the activity and new approaches for implementing the activity. Your comments will be added to the activity under a separate section labeled "Feedback." Comments may be edited.

Editor's Note (2008): This Curriculum Resource was published prior to establishment of current criteria of submission, and as such, does not contain all criteria required of current publications. However, the Editorial Committee felt that the activity itself remained worthwhile and relevant, and encourages potential users to contact the authors for clarification as needed. If you do update this activity for use with your students, and are interested in updating the resource for distribution in the library, please contact ASM at MicrobeLibrary@asmusa.org.

INTRODUCTION

Time Required.
Out-of-class time: As little as 1 to 4 hours per group or as much as 12 to 24 hours per group, depending on assignment.
In-class time: From 30 to 120 minutes, depending on how models are displayed or presented and the size of the class.

Pedagogical Function.
This activity was designed to improve student understanding of the relative sizes, shapes, and structures found in microbes ranging from viruses to small fungi and protists, and to encourage use of metric units such as nanometers and micrometers.

Learning Objectives.
At the end of this exercise, the student will be able to:

1. Use metric units to calculate and compare microbial sizes and genomes at different scales;
2. Build models of a bacterium, a protist and/or a virus to scale, including intracellular organelles or other structural features of the microbe;
3. Explain major features of the organism modeled in a poster or oral presentation.

Background.
Familiarity with units of the metric system, especially nanometers and micrometers. An introduction to microbial structure and function, including at least bacteria and viruses. It may help to review metric units and some examples of how to convert between units, with special emphasis on micrometers and nanometers.

PROCEDURE

Materials.
Ordinary household objects such as: tennis balls, beads, sewing thread, craft items, chicken wire, paper mache, plastic soda bottles, etc. These can either be supplied by the instructor or by the students. Where possible, recycling is encouraged.

Student Version.

1. Choose one microbe to model. This can be a virus, bacterium or unicellular eukaryotes such as yeast or protists. Your instructor may provide additional information to help you with your choice.
2. Build a three-dimensional scale model of your chosen microbe. All models should be built so they are 100,000x (10^5) larger than their actual size. At this scale, 1 micrometer (actual) would be represented by 10 centimeters (scaled). For example, if the modeled organism were actually 0.25 micrometer long, the scale model should be 2.5 cm. long. If the organism were actually 5 micrometers, the scale model should be 50 cm. long.
3. If the model represents a virus, at the scale suggested above, models will be very tiny (in some cases, as big as a bead, a raisin, or a pipe cleaner). In this case, build a second model at a scale 10 times larger (1 micrometer would be scaled to 100 centimeters; 1 nanometer would be scaled to 1 millimeter). The first model will be used to compare the size of the virus with the size of microbial cells; the second model will demonstrate structural features of the virus more clearly.
4. In constructing your model, use commonplace or recycled materials rather than expensive materials. For example, use cut-off plastic soda bottles, a paper towel cylinder, modeling clay, or a variety of other commonly available materials. Try to find materials that are close to the width and length that you calculated.
5. In addition to building a model, you should calculate the length of nucleic acid in your organism and then scale that length to the same size as your organism. Except for certain RNA viruses, this will be DNA. The quantity of DNA is often measured in terms of number of base pairs (bp), or units of kilobase pairs (1,000 base pairs = 1 kilobase pair, or 1 kbp) or megabase pairs (1,000,000 base pairs = 1 megabase pair, or 1 Mbp). One kpb is about 250 nanometers long (0.25 micrometer) and weighs 6.6 x 10^5 daltons. Some viruses contain single-stranded DNA or RNA, whose length is measured in number of bases rather than base pairs.

   Your instructor may ask you to include an appropriate length of thread to represent the length of nucleic acid at the scale of your model. Thread is available in spools of 50 or 100 yards. Measure out the correct length, coil it loosely, and attach it to your model.

6. Prepare a short poster to accompany your model. Include the organism's name, type of organism (virus, bacterium, etc.), genome size and scaled length, and other information required by the instructor, such as major descriptive characteristics (where found, human impact, unusual properties, etc.).

Instructor Version.
Note: Many variations in procedure are possible. We present here one procedure, but encourage instructors to make variations that are appropriate to their teaching context. For further variations, see section E below, "Possible Modifications", where we post handouts that have been used by several instructors.

1. Assign each student or student pair to model one or more microbes. Students can be allowed to choose their organism(s), as long as duplication is avoided to generate diversity. See Appendix 1 for an extensive list of microbes. These may include viruses, bacteria, or unicellular eukaryotes such as yeasts or protists. Students should use their text and other reference materials suggested by you to find pictures or descriptions of the organism, including size and shape. Some Web sources are listed in Appendix 1. Encourage students to find an electron micrograph with a scale bar so that they can visually estimate the dimensions of the organism, or provide photocopies of electron micrographs with scale bars. For example, if the size bar is 1 micrometer long and the organism pictured is about 3 times as long as the size bar, its length is 3 micrometers. You may require them to photocopy a good illustration to present with their model.

2. Instructor's can require either a 3-D scale model of each microbe assigned, or a poster with a 2-dimensional scale representation. All models should be built to the same scale (suggested scale: 1 micrometer = 10 centimeters). For example, if the modeled organism were actually 0.25 micrometer long, the scale model should be 2.5 cm. long. If the organism were actually 5 micrometers, the scale model should be 50 cm. long. Uniformity of scale allows a realistic comparison of models.

3. If the model represents a virus at the scale suggested above, models will be very tiny (in some cases, as big as a bead, a raisin, or a pipe cleaner). In this case, require students to build a second model at a scale 10 times larger (1 micrometer = 100 centimeters; 1 nanometer = 1 millimeter). The first model will be used to compare the size of the virus with the size of microbial cells; the second model will demonstrate stuctural features of the virus more clearly.

4. In constructing the model, encourage students to use commonplace or recycled materials, rather than expensive materials. Encourage creativity, without undue concern about the color or texture of the objects used. For example, students might use cut-off plastic soda bottle, a paper towel cylinder, modeling clay, or a variety of other materials to build a

rod-shaped bacterium. They should try to find materials that are close to the width and length that you calculated.

5. As an extension of the modeling activity, you might ask students to calculate and/or represent the correct length of nucleic acid along with their model, to help compare the different genome sizes for different organisms. Except for certain RNA viruses, this will be DNA. The quantity of DNA is often measured in terms of number of base pairs (bp), or units of kilobase pairs (1,000 base pairs = 1 kilobase pair, or 1 kbp) or megabase pairs (1,000,000 base pairs = 1 megabase pair, or 1 Mbp). One kpb is about 250 nanometers long (0.25 micrometer) and weighs 6.6 ´ 10^5 daltons. Some viruses contain single-stranded DNA or RNA, whose length is measured in number of bases rather than base pairs. Sewing thread can be used to represent DNA at a scale of 10^5 times; or knitting yarn at a scale of 10^6 times.

Information about the amount of DNA or RNA in an organism may be difficult to find in some cases. This number is readily available for most viruses (see "Information sources" below). Typical bacterial size ranges are roughly 1,000,000 base pairs (1,000 kbp) for very small bacteria up to roughly 5,000,000 bp (5,000 kbp) for the most complex bacteria. If students cannot readily find the genome size of a bacterium, one can make ball-park estimates. Genome sizes for most of the bacteria listed in Appendix 1 can be found at the Web databases listed below.

6. Information sources. For viruses, begin with virus chapters in a microbiology text. "The Big Picture Book of Viruses" Website has electron micrographs as well as information about genome sizes for many viruses. For bacteria, the "TIGR Microbial Database" Website lists microbial genomes whose DNA sequence has been completed or is in progress, including size estimates. Microbiology textbooks will have relevant information for some organisms. Other useful references include Bergey's Handbook of Determinative Bacteriology and The Prokaryotes.
The Big Picture Book of Viruses - http://www.tulane.edu/~dmsander/Big_Virology/BVFamilyGenome.html
TIGR Microbial Database - http://www.tigr.org/tdb/mdb/mdb.html

7. Students should prepare a detailed label or short poster for their model, including its name, type of organism (virus, bacterium, etc.), genome size (if required), and other information required by the instructor, such as major descriptive characteristics (where found, human impact, unusual properties, etc.).

8. Students should present their models in class on the date specified by your instructor. Depending on time available and class size, it may be appropriate to ask for short oral presentations; alternatively, models and their posters may be displayed so that students can observe all models. Student attention will be increased if they are directed to collect certain data about each model and turn in some king of assessment sheet.

Safety Issues. Not applicable.

ASSESSMENT and OUTCOMES

Suggestions for Assessment.
For the Student:
Students should be asked to take notes about other models and do some analysis in order to focus their learning about this activity. This sheet can be handed in for grading as part of the exercise. For example, students should record the variety of organisms modeled and their sizes. Depending on time allotted, ask the students to do any or all of the following:

a. Rank the organisms in order of ascending size, from smallest to largest.
b. Within each class (virus, bacteria, protist), list the smallest and the largest organism.
c. Rank genome sizes from smallest to largest.
d. Compare the largest virus to the smallest bacterium, in terms of size and genome complexity.
e. Compare the largest bacterium to the smallest eukaryotic protist in terms of size and structural complexity.
f. Write 1 (or 2) exam questions based on observations from this exercise.
g. What aspects of your organism did you have difficulty modeling accurately? Explain.
h. What were the specific contributions of each member of the group?
i. For each of the other models, list two biological differences between your organism and that organism.
j. Take a group quiz where the name of the microbe is matched to its description.
k. List 3 major concepts you have learned from this exercise.
l. List resources/references used to prepare this material/model.

For the Instructor:
Depending on time allotted and mode of student presentation, you can base the student's grade on a variety of factors, such as:

a. Appropriateness and originality in model preparation.
b. Is the scale accurately calculated?
c. Quality of presentation/poster.
d. Grade for items on student evaluation sheet.

Problems and Caveats.
Here are some problems that we have encountered with the activity.

Finding appropriate size/structure information. If your microbiology text does not have electron micrographs of certain organisms with indication of size, students may have difficulty finding an appropriate electron micrograph. One solution is to have a variety of microbiology texts available as references that students can consult in the lab or library. Photographs of microorganisms on the Web usually lack accurate scale information, so printed sources are preferable.

Finding appropriate estimates of DNA or RNA size is often difficult for bacteria and protists, although usually easy for viruses. The bacteria and protists listed in Appendix I all have genome sizes listed at the TIGR database on the Web (with a couple of interesting exceptions), so this difficulty can be avoided by judicious choice of organisms.

Students often have difficulty in calculating the correct size to scale their models and, especially, the scaled length of DNA or RNA. To avoid this, require students to submit their estimates of scaled sizes for checking, before you allow them to begin construction, and help them to correct their estimates if these are in error.

One of the benefits of this activity is being able to compare viruses, bacteria, and protists all represented at the same scale. One problem with this approach is that, since the size range spreads over more than 3 logs, the smallest models at a uniform scale of 10^5x will be pea-sized, while the largest (especially if the giant 600 micrometer bacterium *Epulopiscium* is modeled) would be 60 meters! The larger the model, the more work and materials are required, creating something of a handicap for modelers of large organisms. One way around this, for viruses, is to require students to build two models: a simple representation of size at 10^5x to be used simply for size comparison with cells, and a second, more detailed model at 10^6x to display structural features of the virus. The smaller eukaryotes such as yeast cells (ca. 5 micrometers diameter) are adequately modeled at 10^5x — such a cell would be 10 cm in diameter, but for larger eukaryotes, displaying the model at only 10^4x may be desirable.

SUPPLEMENTARY MATERIALS

Possible Modifications.
This exercise can be varied in many ways, including the following:

1. Construct an additional 2-D model or diagram to illustrate molecular details of major internal components. Scale may be different than the 3-D model, but must be clearly indicated.
2. In conjunction with the previous step, students will prepare a legend identifying the known functions of each organelle by:
   a. Listing the major biochemical components.
   b. Listing the major known function for each biochemical component.
   c. Listing the consequences to the organism if this structure were lost.
3. Students can present their project to the other students in the class.
4. Students will compose two exam questions covering their organism.
5. Note that chloroplasts and mitochondria are the same size as prokaryotes. Chloroplasts and/or mitochondria could be added to the list of possible models, and the endosymbiotic theory could be integrated into the discussion.
6. If using as an in-class drawing assignment, you may want to require each group to draw all of the assigned organisms in two-dimensions and to scale. This would prevent one group finishing faster than another.

Some of the authors have adapted this activity in various ways. Click any of the pages below to explore their protocols and instructions, and borrow ideas freely to modify the procedure for your own use.

Linda Sherwood - Montana State University, Bozeman, MT

a. Sherwood Webpage - http://www.homepage.montana.edu/~umbls/index.htm

Susan Deines - Colorado State University, Fort Collins, CO

a. Deines Model Page

References.
Instructors should list references available in the school library or other locations (e.g., laboratory) which might help students with this assignment, including microbiology texts and selected journal articles.

Appendices.
Appendix 1. Suggested microorganisms to model.
Here is an extensive list of suggested microorganisms. Depending on the size of the class, you may wish to present only a fraction of these choices to students. With only a couple of interesting exceptions noted below, information about all these organisms is available on the Web in the "TIGR Microbial Database".
TIGR Microbial Database - http://www.tigr.org/tdb/mdb/mdb.html

1. **Viruses:** all except MS2 listed in the "TIGR Microbial Database" Website.
   a. T4 bacteriophage of *E. coli* (ds DNA nonenveloped)
   b. Lambda bacteriophage of *E. coli* (ds DNA nonenveloped)
   c. MS2 bacteriophage of *E. coli* (ss "+" RNA nonenveloped)
   d. Human adenovirus (ds DNA nonenveloped)
   e. Human papillomavirus (ds DNA nonenveloped)
   f. Hepatitis B virus (ds/ss DNA enveloped)
   g. Herpes simplex virus (ds DNA enveloped)
   h. Human immunodeficiency virus (HIV)
   i. Human influenza virus (ss "-" RNA enveloped)
   j. Human poliovirus (ss "+" RNA nonenveloped)
   k. Mammalian reovirus (ds RNA nonenveloped)
   l. Rabies virus (ss "-" RNA enveloped)
   m. Sindbis virus (ss "+" RNA enveloped)
   n. Sin Nombre virus - a hantavirus (ss "-" RNA enveloped)
   o. Tobacco mosaic virus (TMV)
2. **Bacteria:** all, except *Epulopiscium*, listed in the "TIGR Microbial Database" Website with genome sizes.
   a. *Bacillus subtilis*.
   b. *Borrelia burgdorferi*.
   c. *Campylobacter jejuni*.
   d. *Chlamydia pneumoniae*.
   e. *Clostridium acetobutylicum*.
   f. *Epulopiscium fishelsoni* ("giant" bacterium from sturgeon fish intestine, 80 x 600 micrometers)
   g. *Escherichia coli*.
   h. *Haemophilus influenzae*.

i. *Halobacterium salinarium*.
j. *Helicobacter pylori*.
k. *Lactobacillus acidophilus*.
l. *Listeria monocytogenes*.
m. *Methannococcus jannaschii*.
n. *Methanobacterium thermoautotrophicum*.
o. *Mycobacterium leprae*.
p. *Mycobacterium tuberculosis*.
q. *Mycoplasma genitalium*.
r. *Neisseria gonorrhoeae*.
s. *Pseudomonas aeruginosa*.
t. *Pyrococcus furiosus*.
u. *Rickettsia prowazekii*.
v. *Staphylococcus aureus*.
w. *Streptococcus pyogenes*.
x. *Sulfolobus solfataricus*.
y. *Treponema pallidum*.
z. *Vibrio cholerae*.

3. **Eukaryotes:** all, except *Nanochlorum*, listed in the "TIGR Microbial Database" Website with genome sizes.
    a. *Candida albicans*.
    b. *Dictyostelium fiscoideum*.
    c. *Giardia lamblia*.
    d. *Nanochlorum eukaryotum* (one of smallest eukaryotes, only 1 to 2 micrometers in diameter)
    e. *Plasmodium falciparum*.
    f. *Saccharomyces cerevisiae*.
    g. *Trypanosoma b. rhodesiense*.

Curriculum Resources

Deines Model Page

Modeling Microbes to Scale - Lecture and Activity Notes

Susan M. Deines

LECTURE SESSION #1

1. Review some of the metric units used in the measurement of microbes.

 1 cm = 1/100 of a meter = 10^{-2}

 1 mm = 1/1000 of a meter = 10^{-3}

 1 mm (micrometer or micron) = 1/1,000,000 of a meter = 10^{-6}

 1 nanometer (nm) = 1/1,000,000,000 = 10^{-9}

2. Ask the students to imagine a world in which a micron is now the equivalent size of 10 cm. Use the following example:

How large would a mosquito, that is 1 cm long in the "real world," be in this imaginary world?

 a) In the "real world" 1 cm = 10,000 microns;

 b) therefore, in the "real world", a mosquito that is 1 cm long is 10,000 microns long.

 c) In this "imaginary world", 1 micron is the equivalent length of 10 cm;

 d) therefore, a mosquito that is 10,000 microns long in the "real world" is 100,000 cm long in the "imaginary world" (10,000 x 10 cm).

 e) There are 2.54 cm per inch, so 100,000 / 2.54 = 39,370 inches.

 f) There are 12 inches per foot, so 39,370 inches / 12 = 3,280 feet.

 g) Therefore, a mosquito that is 1 cm long in the "real world", would be 3,280 feet long (approximately the length of 3 football fields!) in the "imaginary world."

3. Assign the following problem for students to complete and bring to the next lecture session.

 How large would *Epulopiscium fishelsoni*, the giant bacterium found in the gut of sturgeon fish, be in the "imaginary world"? This bacterium measures over 600 mm in length (600 mm = 0.6 mm) and is therefore large enough to be seen with the naked eye. It is just a little larger than the period at the end of this sentence.

Answer:

 a) Each micron is now the equivalent length of 10 cm, so 600 x 10 cm = 6,000 cm.

 b) 6,000 cm / 2.54 = 2,362 inches.

c) 2,362 inches / 12 = 196.85 feet.

LECTURE SESSION #2

1. Each group of 5 to 6 students receives an electron photomicrograph of two microbes, along with their actual size. It is best to give each group one simple microbe and one complex microbe so that it will be approximately the same amount of time for each group to complete their drawings. Each group of students is asked to determine to which kingdom (if any) "their" microbes belong, if they are a eukaryotic or prokaryotic organism (or neither), and how large they would be in the "imaginary world." I used the following microbes:

Kingdom Fungi:
Mold - *Aspergillus* spores (2-10 mm round)
Yeast - *Saccharomyces cerevisiae* cell (8 mm round)

Kingdom Protista:
Protozoans - *Trichomonas vaginalis* (13 mm long (range is 4-32 mm long) x 5 mm wide)
Paramecium (100 mm long (can be up to 125 mm long) x 50 mm wide)
Algae - Diatom (30 mm round)

Kingdom Monera:
Escherichia coli (6 mm long x 1 mm wide)

Viruses:
Smallpox virus (300 nm)
T2 bacteriophage (100 nm)
Polio virus (27 nm)

2. Once the students had determined how large the microbes were, they were asked to make a rough drawing of the microbes, the size they would be in the "imaginary world," on computer paper.

3. Each group of students presented their drawings to the class. They identified the microbes, the kingdoms to which they belonged (if any), and stated whether they were eukaryotic, prokaryotic or neither.

Answers:

Microbe	Real World Size	Imaginary World Size
Mold - *Aspergillus* spores	2 mm round	20 cm round
Yeast - *Saccharomyces cerevisiae* cell	8 mm round	2.62 feet round
Protozoan-*Trichomonas vaginalis*	13 mm long x 5 mm wide	4.26 ft long x 1.64 ft wide
Paramecium	100 mm long x 50 mm wide	32.8 ft long x 16.4 ft wide

Algae - Diatom	30 mm round	9.8 ft round
Escherichia coli	6 mm long x 1 mm wide	23.62 in long x 4 in wide
Smallpox virus	300 nm	3 cm
T2 bacteriophage	100 nm	1 cm
Polio virus	27 nm	0.27 cm

Assessment Strategies:

1. The students were graded individually on their answers to the original problem concerning *Epulopiscium fishelsoni*.

2. Each group of students was graded on their answers to the following questions regarding "their" particular microbes:

a) What are the names of the microbes?

b) To which kingdoms, if any, do these microbes belong?

c) Are these microbes eukaryotic or prokaryotic (or neither)?

d) What are the "real world" sizes of these microbes?

e) What are the "imaginary world" sizes of these microbes?

f) Calculations used to determine the size in the "imaginary world"?