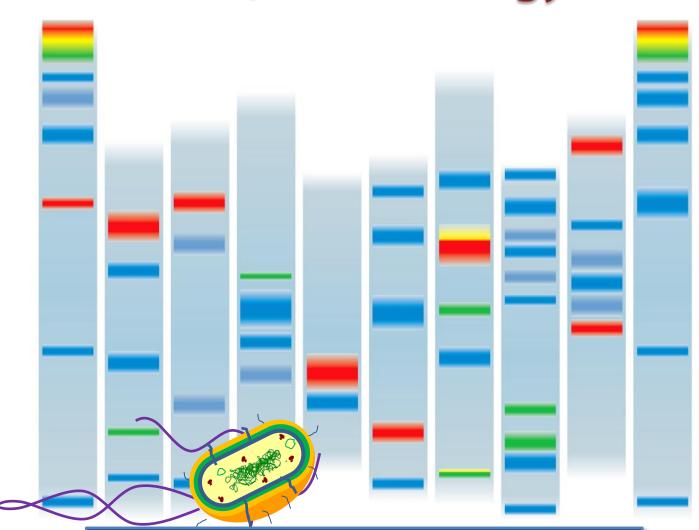# STEM Integration:

Math, meet Biology!

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STEM Integration: Math, meet Biology!
Biology and Geometry: A Telling Image

NOTES

Logistics:

This lesson is intended for students in grades 3 – 5. Students will use a hands-on activity to investigate mathematical concepts and laboratory techniques involved in micropipetting. This will include the study of metric volume (i.e., microliter), a coordinate grid system, and the application of STEM content inherent in biotechnology. Students should be grouped in teams of two to four, depending on the materials available for the activity. This lesson will require the use of water, so access to a classroom sink or bathroom would be ideal.

Materials *per student*:

    1 – copy of Student Pages

    per team of students:

        5 – Small Cups filled with five color solutions
        1 – Small cup for micropipette tip disposal
        1-4 – Fixed Volume Micropipettes (or disposable pipette)
        20-50 – Micropipette Tips (if using micropipettes)
        1 – Well Microplate (96 wells) or adapted templates
        1 – Wax Paper (small sample)
        Pattern Sheets
        Water
        Glue Dots (optional)

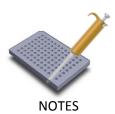   *per class:*

        1 – Box of Food Coloring
        Paper Towels and cleaning supplies

Time: 50 - 60 minute class period

Objectives/Standards:

The objectives of this lesson are to:

- Identify a location on the coordinate plane by using an ordered pair of numbers, or representative values, in reference to perpendicular number lines, called axes. CCSS.MATH.CONTENTS.5.G.A.1, MP4, MP5, MP7, SEP2, SEP3, SEP4, SEP5, CCSS.ELA-LITERACY.RST.6-8.3,

- Perform biotechnology skills in a simulated application using fixed volume micropipettes and a coordinate grid system. CCSS.MATH.CONTENTS.5.G.A.2, MP4, MP5, MP7, SEP2, SEP3, SEP4, SEP5, CCSS.ELA-LITERACY.SL.5.1
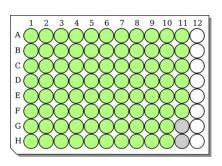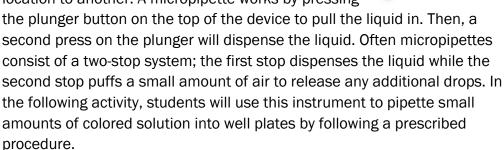
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Introduction:

The field of biotechnology provides learners a unique opportunity to study the mathematics inherent in science. **Biotechnology**, or the use of living systems to develop technologies and products that solve a problem or need, involves the use of many scientific instruments. In the following activity, students will use 96-well microplates, color solutions, and 10 µl micropipettes to complete an integrated mathematics exercise embedded in a biological context.

96-well microplates, often referred to as well plates, microwells, microtiters, or multi-well plates, are scientific tools that are commonly used as small spaces in which to store, manipulate and study solutions. Well plates are a standard tool used in analytical research and clinical diagnostic testing laboratories. These flat plates, made of polystyrene and rectangular in shape, consist of multiple wells that are used as small test tubes. Additionally, the wells of each plate can be identified by using the horizontal and vertical axes, an alpha-numeric coordinate system, found on the outer edge. In the following activity, students will utilize this equipment to investigate coordinate geometry by "painting" an image using a 10 µl micropipette.

Micropipettes are another common instrument used in the fields of biology and biotechnology. These tools are often used in chemical, biological, forensic and pharmaceutical laboratories to transfer small quantities of liquid. These tools use sterile, disposable pipette tips to transfer solutions from one location to another. A micropipette works by pressing the plunger button on the top of the device to pull the liquid in. Then, a second press on the plunger will dispense the liquid. Often micropipettes consist of a two-stop system; the first stop dispenses the liquid while the second stop puffs a small amount of air to release any additional drops. In the following activity, students will use this instrument to pipette small amounts of colored solution into well plates by following a prescribed procedure.

An application of the biotechnology components introduced in this activity is included as an extension. **Gel electrophoresis** is a method of separating compounds based on electrical charge and fragment size. This process is

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used frequently in forensics and molecular biology to confirm that DNA is present and/or cut in the proper format for use. In the included extension activity, students utilize agarose filled gel boxes, Kool-Aid solutions, and 10 μl micropipettes to complete this investigation.

Advanced Preparation:

- ☐ Prepare the color solutions for the students. Please refer to the table below.
- ☐ Pre-designed templates can be found on the Resources page of this document. A summary of how to use each template is provided. These templates are appropriate for students in grades 3 – 5 and have been constructed based on the academic requirements outlined in the Common Core Mathematics Standards at each grade level.
- ☐ Depending on the motor skills of your students, it may be necessary to attach the templates to the well plates before beginning the activity.

Color Solution Preparation Directions					
To Make...	Red	Blue	Green	Yellow	Orange
Drops of Color	5 Red	5 Blue	5 Green	2 Yellow	1 Red 5 Yellow
Amount of Water	30 mL	30 mL	30 mL	30 mL	30 mL

Suggested Inquiry Approach:

Students should be placed in teams of two to four for this activity. This arrangement may depend on access to resources and materials. Student grouping arrangements should be determined prior to the start of the exercise. Provide each student with the appropriate student pages.

Begin the activity introducing the 10 μl micropipette and pipette tips to the students. Allow them an opportunity to manipulate the pipette, investigating its various parts. Assist students as they become comfortable and adept at putting the pipette tips on the micropipette and removing the tips. At this time, explain to the students how the two-stop system dispenses liquid.

NOTES

Biology and Geometry: A Telling Image

NOTES

 Note: Using the hands to secure and remove pipette tips would not occur in an actual lab. Strict procedures and regulations are in place to keep all tips sterile and safeguard the integrity of the experiment.

Ask the students to predict the size of the water droplet that will be dispensed by the micropipette. Students will record this information in their student pages.

Next, provide each group with a piece of wax paper and small cup of water. The students will now pipette 10 µl of water onto the wax paper and compare the actual amount to their predicted drawing. Provide students an opportunity to discuss their observations. The following questions may aid the discussion:

➢ **How did your prediction compare to the actual amount of water dispensed by the micropipette?** [Answers will vary. Typically, students severely underestimate the actual amount dispensed by the micropipette.]

➢ **How much smaller is a microliter compared to a liter? How much smaller are 10 microliters compared to a liter?** [1 million microliters are in a liter. Therefore, a microliter is 1 millionth of a liter. 10 microliters is 1 one hundred-thousandth of a liter.]

➢ **Why do you think scientists would work with a sample of liquid that is this small?** [The biological materials studied by scientists are extracted in their natural forms. This includes basic cellular units and biological molecules. Instruments such as micropipettes are regular tools used in laboratories to manipulate these organisms.]

Next, provide each student group with a 96-well microplate and/or adapted template. These templates, designed to support grade-level academic standards, can be found in the Resource section of this document.

Allow several minutes for students to observe the well plate and record information in the appropriate table within their student pages. Then, host a class discussion to explore the mathematical properties of this instrument:

➢ **What do you notice about the symbols, or values, that stretch across the top of your well plate (or template)?** [The horizontal axis on a 96-well plate includes a numeric scale. Additional templates in this activity have been modified to include symbols.]

➢ **What do you notice about the symbols, or values, that stretch along the side of your well plate (or template)?** [The vertical axis on a 96-well

Note: Directions for attaching the template to the well plate are included in the Resource pages.

An image gallery of the well plates with attached templates can be found on the Google Drive:

goo.gl/V3mOJn

IMSA

4

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NCTM Annual Meeting; April 7, 2017

plate includes an alphabetic scale ranging from A-H. Additional templates in this activity have been modified to include numeric scales.]

➢ **These lines are called "axes". How might you use axes to locate a well?** [Axes are used to define a coordinate system. Locations on the plane are determined by the intersection of the values from each axis.]

➢ **How might you write the location of a well?** [In coordinate geometry, these values are represented as ordered pairs. The first value in the ordered pair represents the *x*, or horizontal value, while the second represents the *y*, or vertical value. Ordered pairs are traditionally written, *(x,y)*.]

➢ **What might we call the point at which both axes meet?** [The intersection of both axes represents the origin. The ordered pair representing the location of each well then indicates how far to travel from the origin in the direction of each axis.]

➢ **Well plates use a coordinate system to locate each well. Have you seen a grid, or coordinate system, before? Did it look the same, or different, from this system? Explain.** [Answers will vary. Students may relate this new understanding of graphing points on a coordinate plane to using a multiplication table. In both instances, students are identifying the point at which the horizontal and vertical values intersect.]

Students may need additional time to become proficient in locating specific wells on their plate. A simple exercise such as calling out a location and asking the students to mark the corresponding well with a sticker dot would allow students practice in working with the instruments and coordinates. Additionally, students may play a "Battleship" style game with a partner by marking and calling out locations.

Explain to the students that they will now receive a Pattern Sheet, which includes a series of locations that when followed, produces a picture. Students will use their 10 µl micropipette and pipette tips to add color solutions to designated well plate locations.

When appropriate, distribute a Pattern Sheet to each group. Allow time for each group to determine how they will complete the pattern by sharing the color solutions, micropipette and pipette tips (if necessary). Encourage students to work together and share responsibility. Explain to the students that new tips should be used for each different color solution used.

Note: Re-using pipette tips would not occur in an actual laboratory. Doing so would contaminate materials.

> **Student Accommodations:** Students needing additional support may use two pieces of uncooked linguini to locate specific wells. By placing one piece of linguini vertically along the designated x-axis value, and another piece horizontally on the designated y-axis value, the intersection of these markers indicates the well of interest.

Biology and Geometry: A Telling Image

Distribute the color samples and well plates when groups are ready. Assist the groups as needed. Also, inform students that they may choose to dispense 20 to 30 μl of color solution into each well.

Students needing accommodations may use an adjusted well plate grid. Instructors may choose to "block" cells that will not be used to complete the pattern by drawing an **x** in those wells. Additionally, students needing support may be provided with a template which includes the well designations (i.e., (4,2)) labeled within some, but not all, wells.

When student groups have completed their Pattern Sheet, encourage each group to share their picture. If a document camera is accessible, students may choose to place a sheet of white paper beneath their well plate and project their image. Allow several minutes to display each image and then reconvene for a whole class discussion.

Debrief questions:

- *Was pipetting easy? Challenging? Explain.* [Answers will vary. Initially, students' motor skills may make this exercise challenging. However, with practice, they should become more proficient.]

- *How did you determine the location in which to pipette each color solution?* [Students will use the locations listed in the Pattern Sheet to identify the corresponding well on the 96-well plate. Each location is listed as an ordered pair, where the first value indicates the point on the horizontal axis and second value indicates the point on the vertical axis. The intersection of these two values indicates the appropriate well.]

- *What surprised you about the volume, or amount of liquid, that was dispensed from the micropipette?* [Answers will vary. Students may have recognized that 20 to 30 μl was an appropriate volume for each well.]

- *What do you think is the volume of one well? How could you determine this value?* [Student predictions will vary. Students may test their prediction by using the micropipette to fill a well with a color solution. Wells typically hold approximately 360 μl.]

- *What other activities might a well plate be used for?* [Well plates are commonly used in a variety of scientific laboratories. They are typically used in analytical research and clinical testing labs.]

- *What materials might a scientist use a well plate to explore?* [Answers will vary. Students may suggest chemicals, DNA, protein, and various other liquids.]

IMSA

6

STEM Integration: Math, meet Biology! Karen Togliatti and Lindsey Herlehy
NCTM Annual Meeting; April 7, 2017

Conclusion:

This lesson is written as a hands-on activity integrating mathematics in a biological context. In many learning environments, mathematics is treated as the study of equations, numbers, shapes, and operations while connections made between this study and other contents are left detached. However, when viewed as a language necessary to make new scientific discoveries, read, write, and perform engineering tasks, mathematics becomes much more essential, substantial, and natural.

Research suggests that instruction composed of authentic interdisciplinary connections invites students at all grade levels to develop a coherent, in-depth understanding of their world. *Biology and Geometry: A Telling Image* engages students in the study of mathematics not as a singular, isolated unit, but as a piece of a larger application through the lens of biotechnology. By engaging in hands-on STEM explorations, students make direct connections to the latest developments in biology, technology, design and mathematical thinking that promote the skills and talents necessary to meet the challenges of college and careers in the 21st century.

According to the Occupational Outreach Quarterly published by the Bureau of Labor Statistics, the number of STEM career opportunities is expected to grow by 12% by the year 2022. This equates to approximately 1 million jobs with a projected median salary of $76,000. As the demand for individuals to fill STEM employment opportunities arise, the need for STEM proficient educational programs becomes critical.

Assessment:

To assess student understanding, provide each student with a blank template of the 96-well plate and small index card. Instruct each student to draw a simple (6-8 wells) design on the blank template. Students should then record the ordered pairs of the corresponding filled wells on the index card. You may then have students exchange pictures and index cards with a partner and use peer assessment to check the accuracy of their work.

Extensions:

❖ Students may continue their study of the mathematics inherent in biology by designing their own pictures and recording the corresponding ordered pairs on a Pattern Sheet. Then, student groups may exchange patterns. A blank template of the 96-well plate is included on the

NOTES

Resources page of this document.

❖ If studying geometric principles, students may be tasked with designing an image that demonstrates symmetry. For example, one group may create one-half of an image, indicate where the line of symmetry falls, and then exchange their image with another group to complete the design.

❖ Students may also put their pipetting skills to use by performing **gel electrophoresis**, a laboratory method used to separate fragments of material such as DNA, RNA, and proteins. A materials list and student pages for this extension are included in a separate document.

Lesson adapted from the Illinois Mathematics and Science Academy, IMSA Fusion: *Synthetic Scorecard*.

Resources:

Lefkowitz, M. (2015, December 1). The M in STEM. Retrieved December 22, 2016, from http://blog.mindresearch.org/blog/the-m-in-stem

National Science Foundation - Where Discoveries Begin. (2014, December 4). Retrieved December 22, 2016, from https://www.nsf.gov/news/news_summ.jsp?cntn_id=133534

Materials:

A Telling Image:

✓ Fixed Volume (10 µl) Micropipette - https://www.grainger.com/product/GRAINGER-APPROVED-Mini-Pipet-8RPJ6?s_pp=false&picUrl=//static.grainger.com/rp/s/is/image/Grainger/8RPJ6_AS01?$smthumb$

✓ Disposable Micropipette Tips - http://cynmar.com/pipets-micropipets-accessories/20206-GRADUATED-PIPET-TIPSUNIVERSAL1-200I-NATURAL1000PK.html

✓ 96-Well Microplate - http://www.phenixresearch.com/products/96-well-nonsterile-ps-plate-clear-u-bottom.asp
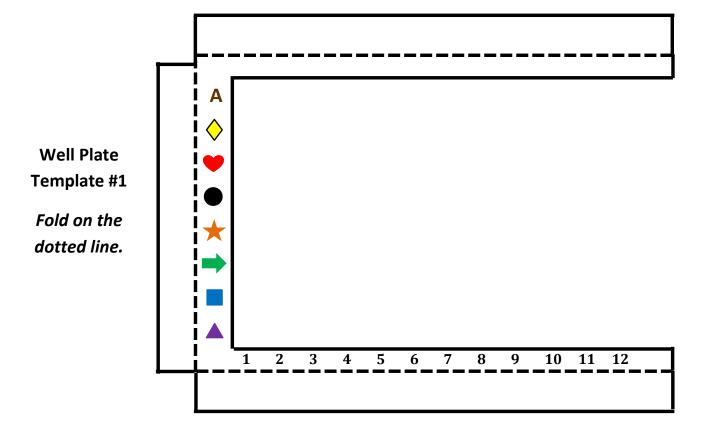
The following resources have been developed in support of the Common Core Mathematics State Standards for grade levels 3-5:

Well Plate Templates 1-3 **provide students with alternate axes which correspond to the vertical and horizontal axes of the traditional coordinate plane. The placement of these axes represents Quadrant I. Instructors should choose an appropriate template to place on the well plate based on the interests and academic abilities of their students. At Grade 5, all students should become proficient in using** Well Plate Template #3 **to locate and document the ordered pair of each well.**
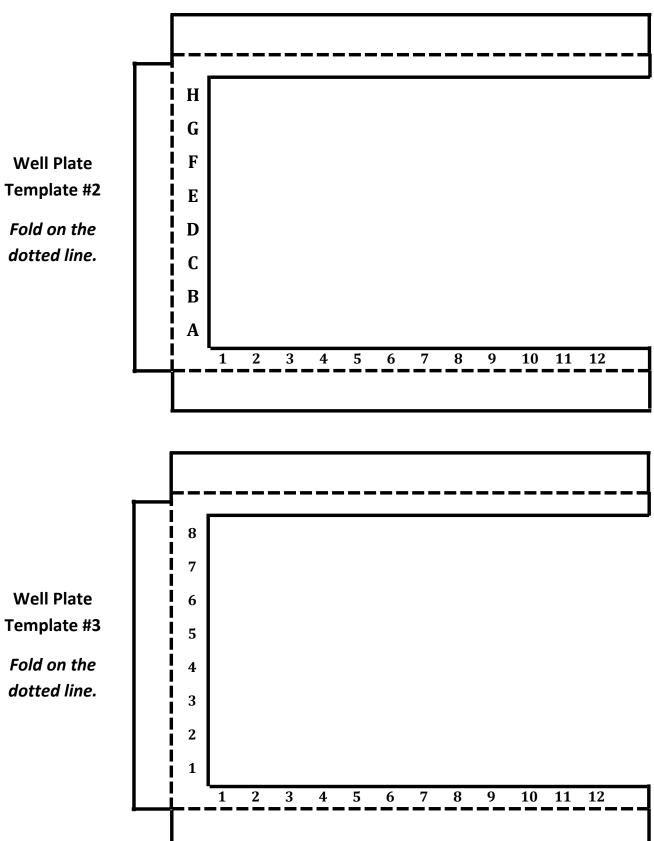
These templates should be printed on white paper. After cutting out the template, fold on the dotted line. Secure the template to the boarder of the 96-well plate using glue dots or tape. Glue dots can be placed on the inner-lip of the template and attached to the side of the plate.

Well Plate Grid 1-3 **can be used in place of 96-well microplates. Print these grids on white cardstock, and if possible, laminate. Alternatively, a piece of wax paper could be secured over the grid. Students may then complete the activity using their micropipettes or disposable pipettes.**

Well Plate Template #1

Fold on the dotted line.

A

1 2 3 4 5 6 7 8 9 10 11 12

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NCTM Annual Meeting; April 7, 2017

Well Plate Template #2

Fold on the dotted line.

H
G
F
E
D
C
B
A

1   2   3   4   5   6   7   8   9   10   11   12

Well Plate Template #3

Fold on the dotted line.

8
7
6
5
4
3
2
1

1   2   3   4   5   6   7   8   9   10   11   12

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NCTM Annual Meeting; April 7, 2017

Biology and Geometry: A Telling Image Resources

Well Plate Grid #1

	1	2	3	4	5	6	7	8	9	10	11	12
A	○	○	○	○	○	○	○	○	○	○	○	○
◇	○	○	○	○	○	○	○	○	○	○	○	○
♥	○	○	○	○	○	○	○	○	○	○	○	○
●	○	○	○	○	○	○	○	○	○	○	○	○
★	○	○	○	○	○	○	○	○	○	○	○	○
→	○	○	○	○	○	○	○	○	○	○	○	○
■	○	○	○	○	○	○	○	○	○	○	○	○
▲	○	○	○	○	○	○	○	○	○	○	○	○

Well Plate Grid #2

	1	2	3	4	5	6	7	8	9	10	11	12
H	○	○	○	○	○	○	○	○	○	○	○	○
G	○	○	○	○	○	○	○	○	○	○	○	○
F	○	○	○	○	○	○	○	○	○	○	○	○
E	○	○	○	○	○	○	○	○	○	○	○	○
D	○	○	○	○	○	○	○	○	○	○	○	○
C	○	○	○	○	○	○	○	○	○	○	○	○
B	○	○	○	○	○	○	○	○	○	○	○	○
A	○	○	○	○	○	○	○	○	○	○	○	○

Well Plate Grid #3

Biology and Geometry: A Telling Image Resources

Pattern Sheet – Template #1

PICTURE 1				
RED	**ORANGE**	**YELLOW**	**BLUE**	**GREEN**
(4 , **A**)	(2 , ●)	(3 , ●)	(4 , ★)	(5 , ♥)
(6, **A**)	(2 , →)	(3 , →)	(5 , →)	(7 , ♥)
(8, **A**)	(3 , ◇)	(4 , ◇)	(6 , →)	
(2 , ♥)	(4 , ▲)	(5 , ●)	(7 , →)	
(2 , ★)	(5 , **A**)	(5 , ■)	(8 , ★)	
(3 , ■)	(6 , ▲)	(6 , ◇)		
(5 , ▲)	(7 , **A**)	(7 , ●)		
(7 , ▲)	(8 , ▲)	(7 , ■)		
(9 , ■)	(9 , ◇)	(8 , ◇)		
(10 , ♥)	(10 , ●)	(9 , ●)		
(10 , ★)	(10 , →)	(9 , →)		

Pattern Sheet – Template #2

PICTURE 2				
RED	**ORANGE**	**YELLOW**	**BLUE**	**GREEN**
(7 , D)	(3 , B)	(9 , G)	(9 , B)	(3 , E)
(7 , C)	(3 , A)	(8 , F)	(9 , A)	(2 , D)
(7 , B)		(9 , F)		(3 , D)
(7 , A)		(10 , F)		(4 , D)
(8 , D)		(7 , E)		(1 , C)
(8 , C)		(8 , E)		(2 , C)
(8 , B)		(9 , E)		(3 , C)
(8 , A)		(10 , E)		(4 , C)
(9 , D)		(11 , E)		(5 , C)
(9 , C)				
(10 , D)				
(10 , C)				
(10 , B)				
(10 , A)				
(11 , D)				
(11 , C)				
(11 , B)				
(11 , A)				

Pattern Sheet – Template #3

PICTURE 3				
RED	**ORANGE**	**YELLOW**	**BLUE**	**GREEN**
(6 , 8)	(3 , 3)	(5 , 6)	(1 , 2)	(7 , 7)
(6 , 7)	(4 , 3)	(5 , 5)	(2 , 1)	(7 , 6)
(6 , 6)	(5, 3)	(4 , 5)	(3 , 2)	(7 , 5)
(6 , 5)	(6 , 3)		(3 , 1)	(8 , 6)
(6 , 4)	(7 , 3)		(4 , 1)	(8 , 5)
	(8 , 3)		(5 , 1)	(9 , 5)
	(9 , 3)		(6 , 1)	
	(4 , 2)		(7 , 1)	
	(5 , 2)		(8 , 1)	
	(6 , 2)		(9 , 1)	
	(7 , 2)		(9 , 2)	
	(8 , 2)		(10, 1)	
			(11, 2)	
			(12, 1)	

Blank Well Plate Template

Blank Pattern Sheet

PICTURE				
Color #1	Color #2	Color #3	Color #4	Color #5

Biology and Geometry: A Telling Image
Student Pages

Challenge: *How can we use mathematics to understand scientific tools and procedures?*

Materials:

- Wax paper
- Cups with color solutions
- Water
- 10 µl Micropipette
- Pipette Tips
- Pattern Sheets
- Cup to dispose used pipette tips
- 96-well plate (template optional)

Procedure:

1. With the members of your group, take turns handling the 10 microliter (10 µl) micropipette and one pipette tip. Record your observations below. Also, draw a picture of the pipette and pipette tip. Label each instrument appropriately.

2. Predict how much you think 10 microliters (10 µl) of water will cover by drawing it in the space below.

3. Listen to your teachers explain how to pipette.

4. Pipette 10 microliters of water onto the wax paper. Describe how your prediction compared to the actual amount.

_____

_____

_____

_____

5. Locate your 96-well plate and template. Spend several minutes observing this instrument. With your partner, record your observations and draw a picture of this tool.

6. How will you identify the location of a specific well within the well plate? Be specific. Draw a picture, if necessary.

_____

_____

_____

_____

7. Once your teacher provides you with a Pattern Sheet, develop a group plan to share pipetting responsibilities. When your group has developed a plan, record it in the space below and share it with your teachers.

_____

_____

_____

_____

8. When your teachers have approved your group's plan, your group may begin pipetting.

9. What picture does your Pattern Sheet make?

_____

Debrief Questions:

- **Was pipetting easy? Challenging? Explain.**

- **How did you determine the location in which to pipette each color solution?**

- **What surprised you about the volume, or amount of liquid, that was dispensed from the micropipette?**

- **What other activities might a well plate be used for?**

- **What materials might a scientist use a well plate to explore?**
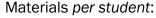
Extension: Gel Electrophoresis

Logistics:

This lesson is intended for students in grades 3 – 5 as an extension to *Biology and Geometry: A Telling Image*. Students will apply their knowledge of biotechnology skills to separate molecules within various Kool-Aid solutions. Students should be grouped in teams of two to four, depending on the materials available for the activity. This lesson will require the use of water, so access to a classroom sink or bathroom would be ideal.

Materials *per student*:

       1 – copy of Student Pages

   per team of students:

       2 – Alligator Clips
       1 – Agarose Gel Box (see Advanced Preparation and Optional
         Mathematics Challenge)
       1 – Graduated Cup
       30 mL – TAE Buffer
       1 – Fixed Volume Micropipette
       2 – Small Paperclips
       6 – Micropipette Tips
       3 – 9 Volt Batteries

   Optional Comb Materials:
   2-4 – Regular-sized Craft Sticks
   2-4 – Narrow Craft Sticks or Wooden Coffee Stirrers
   (approximately .5cm wide)
   Masking Tape
   Ruler
   Scissors

   for the teacher:
       1 – Agarose Tablet per Agarose Gel Box
       1 – Gel Electrophoresis Comb (if not completing the optional activity)
       6 – Packs of Kool-Aid of varying flavors
       6 – Plastic Cups for Kool-Aid
       Microwave and cleaning supplies
       Water

Time**:** 60 minute class period

Note: Additional instructional resources can be found on the Google Drive:

goo.gl/V3mOJn

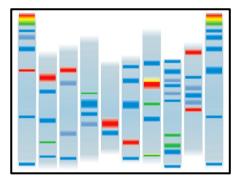# Extension: Gel Electrophoresis

Objectives/Standards:

The objectives of this lesson are to:

- Apply knowledge of biotechnology skills and practices by performing electrophoresis to resolve the colored dye molecules within a sample. CCSS.ELA-LITERACY.SL.5.1, SEP2, SEP3, SEP4, SEP6, SEP7, MP3, MP6, MP7
- Conduct a scientific experiment by precisely following a multistep procedure and performing technical tasks. CCSS.ELA-LITERACY.RST.6-8.3, SEP3, SEP4, SEP7, SEP8, MP3, MP6, MP7

Introduction:

Electrophoresis is a common separation technique used in many laboratories to analyze DNA samples based on electrical charge and fragment size. This process is used frequently in forensics and molecular biology to confirm that DNA is present and/or cut in the proper format for use.

Electrophoresis is conducted through an **agarose gel,** which is a substance extracted from algae or seaweed. This material, usually produced in powered form, is mixed with water, heated and then cooled to form a gel. In this state, agarose is suitable for conducting electrophoresis as it allows different sized molecules to travel through its substance at different rates.

During gel electrophoresis, negatively charged DNA molecules subjected to an electrical field move toward the pole of opposite charge. As this happens, fragments are distributed and settle within the gel based on their fragment size. The smaller the fragment, the faster and farther the distance traveled within the gel. Consequently, larger DNA fragments travel slower and shorter distances.

In the following activity, students will use electrophoresis to examine the colored dye molecules within various Kool-Aid samples. When loaded into the agarose wells and an electrical current is applied, the molecules within these food dye samples will travel within the gel and separate based on their charge and size. When complete, the gel will display the various color bands present within each Kool-Aid sample.

Advanced Preparation:

☐ The agarose gel boxes may be prepared in a Pyrex measuring cup, coffee mug, or 250 mL (or larger) beaker or flask. The gels may be prepared several days in advance and stored with the lid closed. Directions and a checklist for making the agarose gel boxes are included.

☐ Prepare the Kool-Aid samples by mixing each packet with approximately 50 mL of water. It should be very concentrated. Determine how the Kool-Aid samples will be distributed to the students. It may be appropriate to have one central location for these samples where students may take turns collecting their solutions.

Directions & Checklist for Preparing Gels for Run		
CHECK	**STEP**	**INSTRUCTIONS**
	1	Put 1 agarose tablet in 50 mL of water.
	2	Let it sit for 2 minutes or until completely dissolved.
	3	Heat in microwave until it boils. Roughly 45-65 seconds. Allow to boil for about 10 seconds.
	4	Stop. Swirl contents. Heat again for 20-30 seconds.
	5	Stop. Swirl contents. Heat again for 20-30 seconds.
	6	Let the agarose cool for 3-5 minutes. Do NOT let it solidify.
	7	Pour it into a plastic box.
	8	Insert a comb so it rests at a hinge.
	9	Allow the gel to set up. It will turn cloudy when it is setup.
	10	Remove comb once gel is set up. Clean comb in soap and water.
	11	Close box lid and store in refrigerator until ready to use.
	12	Repeat for the other boxes.

Extension: Gel Electrophoresis

Optional Mathematics Challenge: Construct a Comb

As an additional mathematics challenge, students may engineer their own gel electrophoresis comb using basic materials. To complete this challenge, provide students with an empty agarose gel box, two regular-sized craft sticks, two narrow craft sticks or wooden coffee stir sticks, tape and measuring tools. A student page is included for this engineering activity.

Students are tasked with constructing a wooden comb that will be used to set up their agarose gel within the plastic boxes. To begin the activity, instructors may choose to provide students with a visual of a comb used in actual laboratories. Then, following the procedure and requirements listed on the student page, students should work together to accurately measure the craft sticks, mathematically determine the spacing and length of the prongs, and provide a sketch depicting the dimensions of their final product.

Suggested Inquiry Approach:

Students should be placed in teams of two to four for this activity. This arrangement may depend on access to resources and materials. Student grouping arrangements should be determined prior to the start of the exercise. Provide each student with the appropriate student pages.

Begin the activity by hosting a class discussion about DNA and electrophoresis. Refer to the Introduction for more information and answer student questions as needed. The following questions may be posed to the students:

> **What is DNA?** [DNA, or deoxyribonucleic acid, is the carrier of genetic information found in nearly all living organisms. Some students may refer to DNA as the "code of life".]

> **How do scientists study DNA?** [DNA is studied in a variety of ways. In this activity, students will investigate a separation technique, often used to analyze DNA fragments.]

> **Why is DNA analyzed?** [Student answers will vary. DNA is analyzed to determine biological properties, study family relationships, solve crimes and study illnesses.]

Take several minutes to introduce the students to the prepared materials. Provide each group with a prepared agarose gel box, set of alligator clips, TAE buffer sample, 9 volt batteries, and paper towels. Also, inform the students where they will collect their Kool-Aid samples.

It is suggested that the students begin by reading through the procedure listed on the student pages prior to beginning the hands-on investigation. A PowerPoint, complete with an illustration of each step, is included on the Google Drive for this activity. Navigate to: **goo.gl/V3mOJn**.

As a class, work through each step together. Encourage students to record observations in the form of drawings. While the gels are running, pose the following questions for students to consider:

> **What do you think will happen to each of the Kool-Aid samples?** [Answers will vary.]

> **What do you notice is happening?** [As electrophoresis occurs, the molecules within each Kool-Aid sample are being separated based on charge and size. Students should observe that the color dyes that form each Kool-Aid sample are being separated.]

> **What do you think makes the colors separate?** [Student answers will vary. Typically, young students are able to identify the various colors that make up a given Kool-Aid sample, but are not always able to give a scientific explanation of why this occurs.]

When student groups' gels are done running, the power should be disconnected. The gel may still be observed. When it is time to clean all materials, the contents of the gel box may be thrown in the garbage. Alternatively, students may enjoy lifting the agarose gel from the box to observe the colors that have run through the material.

Debrief questions:

▪ *What happened to your Kool-Aid samples?* [Answers will vary. Students should observe multiple samples separating into individual color dyes. Some Kool-Aid samples will separate into more bands than others.]

Extension: Gel Electrophoresis

- *Gel electrophoresis needs a power source. That power source may be batteries or a direct current from an electrical outlet. Why do you think power is needed?* [The electrical source provides a current to pull the negatively charged molecules within the sample. These molecules are pulled toward the opposite, or positive, charge.]

- *Did all of the Kool-Aid samples separate into individual color dyes? Provide evidence to support your thoughts.* [Answers will vary.]

- *How did electrophoresis separate the Kool-Aid samples?* [During electrophoresis, fragments are distributed and settle within the gel based on their fragment size and charge. The smaller the fragment, the faster and farther the distance traveled within the gel. Consequently, larger DNA fragments travel slower and shorter distances.]

- *What other items could we separate with electrophoresis?* [Used in forensics, paternity testing, disease detection and evolutionary relationships among organisms.]

Lesson adapted from the Illinois Mathematics and Science Academy, IMSA Fusion: *Synthetic Scorecard*.

Resources:

"Biology Animation Library." *DNALC Blogs*. N.p., n.d. Web. 05 Jan. 2017. <https://www.dnalc.org/resources/animations/gelelectrophoresis.html>.

"Gel Electrophoresis Overview." *Gel Electrophoresis Overview | Science Primer*. N.p., n.d. Web. 05 Jan. 2017. <http://scienceprimer.com/gel-electrophoresis-overview>.

Materials:

Gel Electrophoresis:

- ✓ Agarose Tablets: https://www.fishersci.com/shop/products/thermo-scientific-fermentas-topvision-agarose-tablets-2/ferr2801#?keyword=FERR2801

- ✓ Comb, Plastic Box, Alligator Clips, Paperclips - http://www.bio-rad.com/en-us/sku/1665085edu-stem-electrophoresis-engineering-module

- ✓ TAE Buffer - https://www.flinnsci.com/electrophoresis-buffer-concentrated/fb0325/
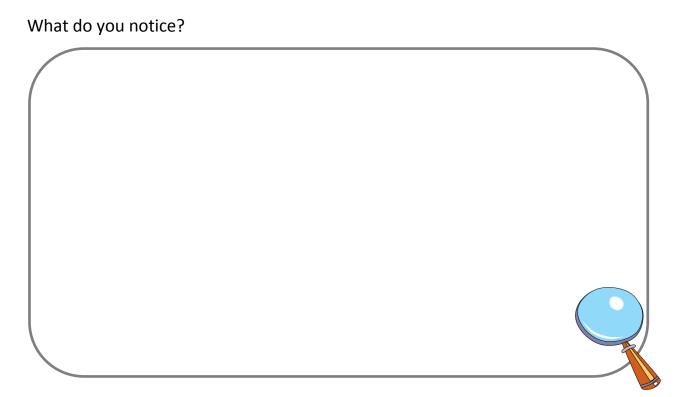
Construct a Comb

Challenge: *Construct a comb that will be used to create wells in the agarose gel box.*

Requirements:
- The comb's handle must extend past the sides of the plastic box.
- The comb must contain 5-6 prongs, all of which fit inside the box.
- All prongs must be equally spaced and cannot touch any part of the plastic box, including the bottom of the box.

Procedure:

Your instructor will provide you with an illustration of a comb used in gel electrophoresis. Take several minutes to observe the image.

What do you notice?

With your partner, use the provided measurement tools to collect information. Answer the following questions, determine the measurements and show all work.

How will you determine the length of your comb's handle?

How will you determine the length of each prong?

How will you determine how far apart you should secure each prong?

Provide a sketch of your comb and label the dimensions. Include the length of the prongs, distance between each prong, and length of the comb's handle.

Gel Electrophoresis

Problem: *How can we separate Kool-Aid samples into individual color dyes?*

Materials:

- 2 Small Paper Clips
- 3 – 9 Volt Batteries
- 2 Alligator Clips
- 1 Prepared Gel Box
- 1 Micropipette
- 6 Pipette Tips
- 30 mL TAE Buffer
- Kool-Aid Samples

Procedure:

1. Listen to your teacher explain how to unfold the paper clip so that it will fit into the plastic box.

2. Carefully unfold the paper clip. Test the paper clip in the empty box to make sure that it fits in the box. Do the same with another paper clip.

3. Set the paper clips to the side.

4. Get your power source ready. Assemble the three 9-volt batteries as instructed by your teacher.

5. Attach one alligator clip to the positive terminal.

6. Attach the other alligator clip to the negative terminal.

7. Set the power source to the side until your team is ready to connect it to the gel box.

8. List the materials that you and your team members will be placing in the wells on the diagram of the gel box on the following page.

9.   As a group, decide who will load which lane.

10. Decide which colors will be loaded into each lane. Record this information on the diagram of the gel box.

11. Carefully touch the gel. Record any observations you have about the gel.

12. Your teacher will help your group cut and remove a thin strip of the agarose gel from the top and bottom of your gel box.

13. Carefully place the paperclips at end of the gel according to your teachers' directions. Be careful to not tear the gel.

14. Measure and pour approximately 30 mL of TAE buffer into the gel box.

15. Once your teachers have inspected your team's setup and given the approval, your team will be ready to move ahead to the next step.

16. Take turns loading the lanes in the gel with the materials available. Fill each lane with _____ of liquid.

17. Have your teachers assist you when it is time to attach the power source to your gel box.

18. Observe the gel box for several minutes.

19. The procedure that you are completing is called **gel electrophoresis**. While your group is watching the process, discuss ideas about what is happening and why it is happening. Think about ideas such as why a power source is needed and why the negative terminal of the battery is by the lanes where the colors were loaded.

20. Record your observations on the diagram of the gel box.

Observations:

Debrief Questions:

- **What happened to your Kool-Aid samples?**

- **Gel electrophoresis needs a power source. That power source may be batteries or a direct current from an electrical outlet. Why do you think power is needed?**

- **Did all of the Kool-Aid samples separate into individual color dyes? Provide evidence to support your thoughts.**

- **How did electrophoresis separate the Kool-Aid samples?**

- **What other items could we separate with gel electrophoresis?**

STEM Integration: Math, meet Biology!
Come Scale Away

Logistics : The activities in this unit of lessons are intended primarily for students in grades 4 or 5 and can be completed in a traditional classroom or science classroom. Students will explore very large and very small objects in relation to powers of ten, and will develop a model of an *E. coli* bacterium's relative DNA contour length. Students will work in teams of two to three for these activities.

Materials: *Powers of 10 Introduction Materials:*
   for each student:
      1 – *Powers of 10* template with six cut-out zeroes
      1 – Computer with Internet Access (optional)
      1 – Copy of Student pages

Powers of 10 Sorting Activity Materials:
   for class:
      10 – *Clue Cards*
      5 – *Metric Measure Cards*
      1 – 10 m piece of string, to be tied across classroom
      5 – Wooden clothespins for Metric Measure
   for each student or team of students:
      1 – Computer with Internet Access (optional)
      1 – *Sorting Card (there are twenty cards to divide among students)*
      1 – Wooden clothespin
      Student pages

DNA Scale Materials:
   for each partner team:
      1 – Meter stick or metric measurement tape
      1 – Pair of scissors
      1 – Snack-size plastic baggie
      1 – Spool of thread (ideally 100 m or ~110 yds)
      (can be purchased online from JoAnn Fabrics
         at http://www.joann.com/gutermann-26-spool-thread/9284811.html)
      7 – Post- it sticky note sheets
   for each student:
      1 – Copy of Student Pages

Estimated Time:
Powers of 10 Introductory Activity: 60 minutes
Powers of 10 Sorting Activity 2: 60 – 90 minutes
DNA Scale Activity: 90 minutes

Come Scale Away

Objectives/Standards

The objectives of these lessons are to:

- Investigate patterns when multiplying and dividing by powers of 10. CCSS.Math.Content.5.NBT.A.2, CCSS.Math.Practice.MP2, CCSS.Math.Practice.MP5, CCSS.Math.Practice.MP7
- Analyze a series of objects on the basis of their length from smallest to largest given a set of photos not to scale. CCSS.ELA-Literacy.RI.5.4, ELA-Literacy.W.5.1.C, CCSS.Math.Practice.MP2, CCSS.Math.Practice.MP3
- Explain the meaning of the metric prefixes kilo-, milli-, micro-, and nano-, in terms of powers of 10. CCSS.Math.Content.4.MD.A.1, CCSS.Math.Content.5.MD.A.1, CCSS.Math.Content.5.NBT.A.2, CCSS.Math.Practice.MP6
- Model the length of DNA in an *E. coli* bacterium. MS-LS1-1, SEP2, Crosscutting Concept: Scale, Proportion, and Quantity; CCSS.Math.Content.5.MD.A.1, CCSS.Math.Content.6.RP.A.3d, CCSS.Math.Practice.MP2, CCSS.Math.Practice.MP4, CCSS.Math.Practice.MP5
- Discuss the use of models including their benefits and limitations. CCSS.ELA-Literacy.SL.5.1, ELA-Literacy.W.5.1.C

Introduction

E. coli (*Escherichia coli*) is a common prokaryote cell (single-celled organism) that can be found inside many other organisms, including humans. In human hosts, *E. coli* live inside the intestines and function to digest food and break it down into smaller molecules. Typical of prokaryotic cells, *E. coli* cells do not contain a nucleus. Instead, the genetic material (DNA and RNA) is suspended in the cell's **cytoplasm** along with **ribosomes** that build proteins by transcribing DNA and translating RNA. In addition to the **chromosomal DNA** which is usually spread in a single strand throughout the cytoplasm or condensed into an area referred to as a nucleoid, *E. coli* also contain small, separate rings of DNA called **plasmids** which can be transferred by **pili** between cells. These pili are small projections extending from the **plasma membrane** which act as pathways between two or more prokaryotic cells and allow for cell conjugation. Bacterial conjugation is a method that allows *E. coli* to transfer genetic material to other cells. Another feature of most *E. coli* cells are long strands of protein that extend off of the cell and aid in motion of the cell called **flagella**.

E. coli is a rod-shaped bacterium that, in addition to yeast, is engineered by

synthetic biologists to produce useful substances. The size of the *E. coli* bacteria is in the order of 1μm width × 3μm length. The symbol μ, which is the Greek letter, mu, stands for the metric prefix "micro". The meter (m) is the basic unit of length in the metric system, and a micrometer is one millionth of a meter. So, while it may be easy for students to visualize something that is one meter in length, it is much more difficult to imagine something that is one-millionth smaller than that! When we then talk about organisms at the nanoscale, such as the rhinovirus, we are talking about billionths of a meter in size.

Furthermore, the contour length of the chromosomal DNA of the *E. coli* bacterium (if it was fully extended) is about 1.5 mm. (*Source: BioNumbers Database ID: 110184*) For a cell with a length of 3 μm, this amounts to a DNA length that is approximately *500 times longer than the length of the organism*! Even with the amount of DNA contained within the E. coli bacterium, there is an upper limit to the size of DNA that these cells can take in and copy. This is a concern facing synthetic biologists, who are researching new ways to improve large gene delivery to host cells.
(*source: Synthetic Life: Dr Dan Gibson Discusses the Science of Big DNA*)

In this set of activities, students will develop a number line model to investigate their idea of size of various items. Students will first explore patterns found in a table of powers of 10, and will use a tool to help understand how to multiply and divide using powers of 10.

Next, students will create a logarithmic number line using the "Powers of 10" and will initially attempt to order the items on the number line from smallest to largest by length using metric prefixes as guides. Then, students will receive a series of clues designed to assist them in their ordering scheme. When the class believes that they have all items ordered correctly, a whole-class discussion will follow in which students discuss their rationale for placement on the number line and if they were surprised by any of the actual sizes of items. Following the initial scaling activity, students will view an interactive online model that shows magnification of items down to the nanoscale.

Students will next focus on the *E. coli* bacterium and will use a physical model to get a sense of how "much" DNA is contained within an organism whose size is at the microscale level. Students will use understanding of the relative powers of 10 to calculate the contour length of "DNA" to place inside their *E. coli* "plasma membrane".

Come Scale Away

Activity 1: Powers of Ten Introduction

Advanced Preparation

- ☐ Prior to students completing this activity, be sure to print on 8 ½" x 11" cardstock the *Powers of Ten* templates.
- ☐ Cut apart into three sections, and then using an *Exacto* blade, cut all of the vertical edges of the squares indicated by dotted lines.
- ☐ Cut apart 1-inch strips, lengthwise, of another sheet of 8 ½" x 11" color cardstock.
- ☐ Take two strips and tape together to form a 22-inch strip. Then, weave the strip through the template with the color showing in the centers of the squares.
- ☐ Center the strip in the template, and then write the number 1 in the center square (to the left of the decimal point).
- ☐ Cut apart additional 1-inch squares and write the number "zero" on each square. Six squares will be required for each template.

To begin the activity, provide each student or pair of students with one *Powers of Ten* template and six "zero" squares. Ask students to observe the tool for a few minutes, and then ask the class to share their observations. Students should notice that there is a decimal point on the non-movable part of the template, and the long strip of paper can slide back-and-forth and move the printed number "1" on the strip.

Questions to ask students at this point in the activity:

- ➢ **What do you think the squares represent on the tool?** [Place value]

- ➢ **What does the small circle represent?** [The decimal point]

- ➢ **Why do you think the number 1 moves back and forth?** [Models an operation or operations on the number 1]

- ➢ **What operations might we use this tool to model?** [Multiplication and division]

- ➢ **What is the purpose of the zeroes?** [Place holders]

Pass out the student pages for *Part 1* of Activity 1 and allow students time to work along with a partner on the questions using the template tool.

Provide adequate time for students to explore using the tool, and then ask the following questions:

➢ **What patterns did you notice when multiplying the number 1 by 10? When dividing?** [A typical response will focus on the number 1 "moving" to the left and adding zeroes when multiplying, and moving to the right and potentially removing zeros when dividing.]

➢ **Does the pattern change when the number 1 is to the right of the decimal point?** [Students may notice that when the number 1 is to the right of the decimal point, the placement of zeroes may not follow the "rule" they thought when multiplying and dividing to the left of the decimal point.]

Now, pass out the student pages for *Part 2* of Activity 1. With a partner, students should observe the table and make connections between the information from column to column as well as the information in each row. The highlighted row represents a "base" for the measurement activity that will follow. Students may question what the little number is called in the "Exponential Form" column. It is fine to let them know that this number is referred to as an **exponent** (or power, or index). Students may question why zero is the exponent for the standard form of the number 1. Direct them to look at the pattern of exponents in relation to the number of 10s that are multiplied together. Students should record their observations and should note that items in a row have the same value. Values in columns increase as they "move" up the column (multiply) and decrease as the values "move" lower down the column (divide).

After student partner teams have had adequate time to discuss their findings in the table, debrief the activity.

Debrief Activity 1:

▪ *What patterns did you observe in the table?* [Answers will vary.]

▪ *Do any of the patterns you noticed using the tool also show up in the table?*

▪ *How does the exponential form of the number relate to its base 10 form?* [For the exponents greater than zero, the exponent shown how many times to multiply the number 1 by 10 (how many 10s to multiply).]

▪ *What do you think the "−" means in the exponential forms of the fractions?* [Multiply the number of 10s shown by the exponent, but in the denominator of a fraction.]

Come Scale Away

Activity 2: Powers of Ten Sorting Activity

Advanced Preparation

☐ Decide ahead of time where to locate and secure the string for the sorting activity.

To begin this activity, pose the following questions to students and ask them to think about their answers quietly for a moment before they begin sharing with the class:

➢ **What is the largest object or item you can think of? How big is it?**

➢ **What is the smallest object or item you can think of? How small is it?**

On the board or chart paper, record student responses. Then, ask students to choose what they believe is the largest item on the list as well as the smallest item. Then, ask students to estimate HOW MANY TIMES bigger the larger item is compared to the smaller item. Allow students to work in teams of two to three students to determine their response to this question.

Focus on student responses such as "it is 100 times bigger" or "1000 times bigger" and ask them to describe how they might determine exactly how many times "bigger" one object is in comparison to another.

Following student discussion, show a meter stick to students. Students at this age should be familiar with the centimeter representing 1/100 of the meter stick and a millimeter representing 1/1000 of the meter stick. They may also know that 1 kilometer would represent 1000 meter sticks. Ask students to share what they know about representing larger and smaller units of length using the meter as the standard length.

Next, provide each student with a Metric Table and allow students time to record observations about the information in the table and share their observations with a team of up to four students. If students have completed the first activity, allow them to make connections between this table and the one they observed connecting exponents to multiplication. Looking back at the list of largest and smallest items students generated, ask them to mark the items along the scale where they believe they would

"fit." Have the students come to a consensus before continuing the activity.

Prefix	Abbreviation	Power of 10	× "bigger" than base
giga	G	10^9	1,000,000,000
mega	M	10^6	1,000,000
kilo	k	10^3	1,000
hecto	h	10^2	100
deka	da	10^1	10
meter	m	Base: 10^0	1
deci	d	10^{-1}	0.1
centi	c	10^{-2}	0.01
milli	m	10^{-3}	0.001
micro	μ	10^{-6}	0.000001
nano	n	10^{-9}	0.000000001

As can be seen in the table, all metric prefixes are powers of 10. To "move" between units, we are either multiplying or dividing by powers of 10. Students in fourth and fifth grade may not have been exposed to seeing numbers written as exponents, especially negative exponents. To introduce this idea, have students start with *1* meter. To move to the dekameter, multiply by 10, so 1×10 or 10^1; to move from the meter to the hectometer, multiply by 100, or 10×10 or 10^2; to move from the meter to the kilometer, multiply by 1000, or 10×10 x 10 or 10^3, etc. Now to move from the meter to the decimeter, which is a smaller unit, divide by 10; so $1 \div 10 = 0.1$ or 10^{-1}; to move from meter to the centimeter, divide by 100 or $1 \div (10 \times 10) = 0.01$ or 10^{-2}. Similar patterns arise moving between the centimeter to the millimeter (a change of 10^{-1}) if we are using the centimeter as the base instead of the meter.

It is highly recommended to complete Activity 1 prior to this activity, especially with younger students.

Come Scale Away

Now, hang the 10 m piece of string across the room at a height that students can reach the top.

CAUTION

 Remind students to be cautious moving around the classroom once the string is hung.

Show the series of five *Metric Measure* cards and ask for volunteers to <u>equally space</u> the cards along the string from smallest to largest using the clothespins to secure the cards to the string.

Activity Modification: There are twenty possible cards available for use. Alternatively, you can select fewer cards and have students work in teams to place cards. *Clue* cards can be modified to reflect the reduction in *Sorting* cards or additional *Clue* cards can be generated.

Place students into teams of two or three. Pass out *Sorting* cards randomly to each team (there are a total of 20 cards) and one clothespin for each card. Students are to look at the item on the card and read the description below the picture. Then, students will decide where to place the item along the "number line" based on the dimension described on the card. If desired, you may tell them that four cards will fit into each "section" of the number line between *Metric Measure* cards with no item smaller than the nanometer. Four cards will be larger than one kilometer.

After the initial sort, assign students into partner teams and give each team a *Clue* card. Have each team read their clue card aloud and make any changes along the number line that they feel are appropriate. Once all of the clue cards are read, ask students to take one more look at the number line to see if any changes should be made. Now, share the actual size of the items:

Item Description	Measurement
The length of one nucleotide base	About 1 nm
The width of a DNA double helix	About 2 nm
The diameter of a rhinovirus	About 30 nm
The length of the Ebola virus	About 800 nm
The length of an E. coli bacterium	About 3 µm
The diameter of a Baker's yeast cell	About 5 µm
The width of a red blood cell	About 7.7 µm
The width of a single strand of human hair	About 90 µm
The length of one sesame seed	About 3.5 mm

The length of an ant	About 6 mm
The diameter of one M&M candy	About 13.6 mm
The length of a pencil	About 190 mm
The length of an average baseball bat	About 1 m
The length of a Boeing 747 airplane	About 71 m
The length of a football field	About 110 m
The height of the Willis Tower	About 442 m
The length of the Golden Gate bridge	About 2.737 km
The distance across the Grand Canyon	About 16 km
The length of a highway	About 4,666 km
The distance between Earth and a GPS satellite	About 20,200 km

Sources: bioNumbers , gps.gov, and Wikipedia

Activity 2 OPTIONAL (15 minutes): In pairs or individually, have students navigate to the following website: http://www.cellsalive.com/howbig.htm . For every five clicks on the magnification arrows, students will increase (or decrease) the magnification by a power of 10. Students can hover over the different names of the items in the animation to see the key for what that item looks like in the animation. Also, if students scroll down to the bottom of the webpage they can find information on the "Cast of Characters" that are highlighted in the animation.

Debrief Activity 2:

- *What item's size surprised you? Why?* [Answers will vary]
- *Were some items harder to order than others? Why?* [Answers will vary]
- *Why are we using powers of 10 for the number line?* [The sizes of the items differ by large amounts. We are using a model to show the items from smallest to largest.] *If we were counting by "meters" would the cards for the powers of 10 be equally spaced along the number line? Why or why not?* [No. All of the items smaller than one meter would be very close together, and the card for the kilometer would be placed very far away from the card for the meter. We would need to measure using 1000 meter sticks to place the card for the kilometer.]

Come Scale Away

Activity 3: DNA Scale

Prior to beginning this activity, it may be interesting for students to view the following video originally created in 1977 (an oldie but a goodie):

https://www.youtube.com/watch?v=0fKBhvDjuy0

From the video introduction:

> "Powers of Ten takes us on an adventure in magnitudes. Starting at a picnic by the lakeside in Chicago, this famous film transports us to the outer edges of the universe. Every ten seconds we view the starting point from ten times farther out until our own galaxy is visible only as a speck of light among many others. Returning to Earth with breathtaking speed, we move inward- into the hand of the sleeping picnicker- with ten times more magnification every ten seconds. Our journey ends inside a proton of a carbon atom within a DNA molecule in a white blood cell. "

Pass out the student page titled *What are E. coli bacteria?* Allow students to read the background information or read the background information aloud to students. Have students observe the cross section of the *E. coli* bacterium and record their hypotheses for the function of each highlighted component of the organism.

Some additional information on *E. coli* bacteria can be found at http://scienceforkids.kidipede.com/biology/cells/ecoli.htm and information on the cell structure of prokaryotic cells can be found at http://www.shmoop.com/biology-cells/prokaryotic-cells.html .

Now, group students into partner teams or teams of three and allow each team to share their ideas of the function of each of the components of the cell that are listed on the diagram of an *E. coli* bacterium. Once teams have shared, provide each team with 7 sticky note sheets. Ask teams to write the function of each cell component on a separate sticky note. Then, on the board or chart paper, list each component from the student pages (Plasma membrane, flagella, pili, cytoplasm, ribosome, DNA, and plasmid). Allow students to come to the board and place their sticky notes under the cell component's name that corresponds to the team's hypothesized function.

Once all of the sticky notes have been placed under the headings, read all of the hypotheses aloud to the class and allow the group to come to a consensus on the function of the particular component under analysis.

Continue until students have defined all of the cells structures listed on the diagram.

Some questions to pose if students still seem unsure about the function of the component are as follows:

➢ **Does the diagram give you any clues as to what the function of the cell component might be?**

➢ **Did most of the partner teams agree on the function of the cell component we are discussing? If there is disagreement, how might we be able to come to a group consensus?**

➢ **Does the function of the cell component relate to any other type of cell structure that you have previously studied?**

Once students have defined the function of the various cell components, it is desired to focus on the chromosomal DNA contained within the cell.

Pass out the next two student pages and read the problem statement aloud. The materials section is purposefully left vague so that students have the opportunity to brainstorm some materials that they could use to model both the plasma membrane as well as the chromosomal DNA contained within a single *E. coli* organism.

Read the following aloud with the students:

In Activity 2, you learned that it is very difficult to imagine things at very large and very small scales. Therefore, we can make models to help us understand very large and very small objects. An *E. coli* bacterium is about 3 μm (micrometers) in length (not including the flagella). However, the DNA stored inside the organism is about 1.5 mm (millimeters) long if it was stretched out.

Ask students to describe the "shape" of the DNA that is clustered within the cytoplasm of the cell. Then, ask students to generate a list of items that they might use to model the DNA in the cell (yarn, spaghetti, string, etc.) and the plasma membrane (box, container, bag, plastic egg, etc.). Allow students to share their ideas. Then, tell them that they will be using thread to model the DNA in the *E. coli* bacterium and a snack-size baggie to represent the plasma membrane.

Come Scale Away

NOTES

With their team, students will try to calculate **how many times larger** the contour length of the DNA strand is in relation to the length of the *E. coli* bacterium. Students will first need to determine how to work with the metric prefixes and must realize that there are 1000 *μ*m in 1 mm. So, compared to the 3 *μ*m length of the bacterium, the DNA is 1,500 *μ*m in length; dividing DNA length by bacterium length yields the approximately 500 times larger results as stated in the background information. Debrief each team's calculation before moving on to the next part of the activity.

Student partner teams will next determine how much of the "DNA" thread they will need to stuff inside the "Plasma Membrane" baggie. If students are struggling, remind them that they already determined how many **times** larger the contour length of the DNA is compared to the bacterium length. Therefore, students can measure the snack-size baggie's length and then convert to an appropriate measure (most likely in meters). The conversion 1000 mm = 1m may be useful here, or 100 cm = 1 m. Snack-sized baggies are approximately 16.8 cm in length. Therefore, students will need to place approximately 84 m of thread (16.8 cm x 500 = 8,400 cm = 84 m) into the baggie. Allow students to predict whether or not they can fit the string inside the baggie BEFORE handing out materials.

Now, provide each team with a snack-size baggie and, ideally, a 100 m spool of thread. Provide scissors if requested. Encourage students to use an efficient method to measure and place the "DNA" into the "plasma membrane".   Also, encourage students to make observations about how they are manipulating the thread inside of the baggie.

Debrief Activity 3:

- *Were you successfully able to fit all of the thread "DNA" into the model? Why or why not? Is there room for the other parts of the cell?* [Answers will vary. However, students should note that the thread can easily fit inside the "plasma membrane" if it is twisted or wrapped.]

- *What are some advantages to using a model to describe something that is very small?* [Answers will vary. Students may reference that this model allows us to get an idea of how much DNA is in the one cell of the bacteria. They may not realize how long a strand of DNA actually is without a model] *What are some disadvantages?* [In this model, we don't really look at the width of the DNA strand; just the length. Also, the other cell components are not included in the model.]

Conclusion:

After students have completed both activities in this unit, the following questions may be used to debrief the entire unit of study:

- How difficult do you think it must be for biologists to work with organisms that are so very small? Why?

- Why might biologists be interested in the relative size of DNA contained within a single-celled organism?

- What other "things" can we use powers of 10 to measure?

This set of activities allows students to explore mathematical manipulations using powers of ten in a context which provides relevance to the topic. Measurement on both a large and small scale uses powers of ten, and both the sorting activity and DNA scale activity give students a scientific application of the mathematics they are expected to learn.

This lesson is adapted from the Illinois Mathematics and Science Academy's IMSA Fusion *Synthetic Scorecard* Curriculum.

Assessment:

Student performance on these activities can be assessed through various formative assessment strategies. Throughout the lessons, opportunities arise for questioning as specified in the activity teacher pages. Other assessments include having students model several different powers of ten using their templates, performing conversions between metric measurements on an exit slip, and providing a list of objects for students to sort in which the object's measurement is listed as a power of ten. Students may also continue adding different scaled parts of the bacterium to the DNA scale model.

Extension:

- ❖ If students are interested, they can research how "much" DNA is in every cell of the human body. An interesting website looks as this question in depth: http://hypertextbook.com/facts/1998/StevenChen.shtml

Come Scale Away

Resources:

BioNumbers - The Database of Useful Biological Numbers. (n.d.). Retrieved January 27, 2015, from http://www.bionumbers.hms.harvard.edu/
BioNumbers Database ID 110184

Synthetic Life: Dr Dan Gibson Discusses the Science of Big DNA. (2013, July 5). Retrieved January 27, 2015, from http://www.idtdna.com/pages/decoded/decoded-articles/your-research/decoded/2013/07/05/synthetic-life-dr-dan-gibson-discusses-the-science-of-big-dna

Picture Websites

DNA - http://commons.wikimedia.org/wiki/File:A-DNA,_B-DNA_and_Z-DNA.png
Ebola - http://commons.wikimedia.org/wiki/File:Ebola_Virus_%285%29.jpg
Rhinovirus - http://www.rcsb.org/pdb/explore.do?structureId=1aym
Nucleotide base - https://openclipart.org/detail/33901/ctp-by-j_alves
Hair - http://creationwiki.org/File:Microscopic_Hair_Strand.jpg
Yeast - http://creationwiki.org/File:Saccharomyces_cells.jpg
E.coli - http://creationwiki.org/File:800px-Escherichia_coli.jpg
Red blood cells - http://www.clker.com/clipart-336782.html
M&M - http://www.clipartpanda.com/categories/dixie-cup-clipart
Sesame Seeds - http://commons.wikimedia.org/wiki/File:Sa_white_sesame_seeds.jpg
Pencil - https://openclipart.org/detail/19488/pencil-by-shokunin
Ant - https://openclipart.org/detail/1581/ant-by-aurium
Baseball Bat - https://openclipart.org/detail/8299/baseball-bat-by-gerald_g-8299
Plane - https://openclipart.org/detail/183204/plane-red-by-sketchartist-183204
Football Field - http://www.wpclipart.com/recreation/sports/football/football_2/football_field.png.html
Willis Tower -http://states.phillipmartin.info/illinois/illinois_willis.htm
Golden Gate Bridge - http://vector-magz.com/building/golden-gate-bridge-vector-item-5/
Highway - http://www.freepik.com/free-vector/interstate-highway-sign-clip-art_378433.htm AND https://openclipart.org/detail/15567/open-road-by-incessantblabber
Satellite – https://openclipart.org/detail/189753/satellite-orbiting-earth-svg-by-unsalted38-189753
Grand Canyon - http://states.phillipmartin.info/arizona/arizona_grand_canyon.htm

Part 1: Multiplying and Dividing by 10

Set up your new tool with the movable number 1 next to the decimal point as shown below:

			1.			

1. Begin by **multiplying** the number 1 by 10. $1 \times 10 = $ _____
    Represent this number on the tool. Move the number 1 to the correct box and add a zero if necessary.

			.			

   Which direction did you move the number 1? _____

   How many "squares" did you move the number 1? _____

   How many zeroes did you place on the tool? _____

   How many 10s did you multiply by? _____

2. Now, **multiply** your answer from the last question again by 10. Represent this number on the tool. Move the number 1 to the correct box and add a zero if necessary.

			.			

   Which direction did you move the number 1? _____

   How many "squares" did you move the number 1? _____

   How many zeroes did you place on the tool? _____

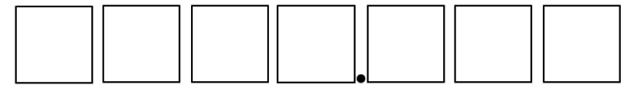   How many 10s did you multiply by? _____

3. Now, **divide** your answer from the last question by 10. Represent this number on the tool. Move the number 1 to the correct box and remove a zero if necessary.

Which direction did you move the number 1? _____

How many "squares" did you move the number 1? _____

How many zeroes did you remove from the tool? _____

How many 10s did you divide by? _____

4. Remove all the zeroes and place the 1 back to the original position as shown below.

1

5. **Multiply** the number 1 by 100. $1 \times 100 = \underline{\quad\quad}$

   Represent this number on the tool.   Move the number 1 to the correct box and add zeros if necessary.

Which direction did you move the number 1? _____

How many "squares" did you move the number 1? _____

How many zeroes did you place on the tool? _____

How many <u>10s</u> did you multiply by? _____

6. Now, **divide** your answer from the last question by 100. Represent this number on the tool. Move the number 1 to the correct box and remove a zero if necessary.
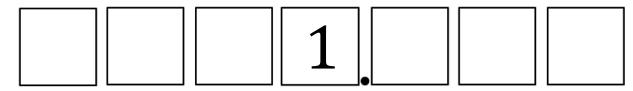

Which direction did you move the number 1? _____

How many "squares" did you move the number 1? _____

How many zeroes did you remove from the tool? _____
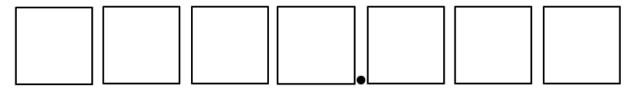
How many 10s did you divide by? _____

7. Remove any zeroes and place the 1 back to the original position.

8. Calculate the following problem. Record your answer as a decimal:

$$1 \div 10 = _____$$

Represent this number on the tool.

Which direction did you move the number 1? _____

How many "squares" did you move the number 1? _____

How many zeroes did you place on the tool? _____

How many 10s did you divide by? _____

9. Calculate the following problem. Record your answer as a decimal:

$$1 \div 100 = \underline{\hspace{2cm}}$$

Represent this number on the tool.

Which direction did you move the number 1? _____

How many "squares" did you move the number 1? _____

How many zeroes did you place on the tool? _____
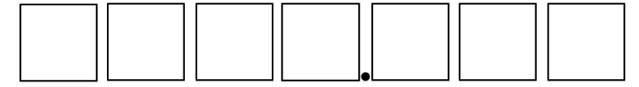
How many <u>10s</u> did you divide by? _____

10. With your partner, explore different problems multiplying or dividing by 10. Try placing the 1 at different points along the tool to start.

Discussion Questions

1) What patterns did you notice when multiplying the number 1 by 10?

When dividing?

2) Does the pattern change when the number 1 is to the right of the decimal point? _____ Explain your answer.

Part 2: Powers of 10 Observation Table

With your partner, observe the patterns in the table below:

Standard Form	Base 10 Form	Exponential Form	Decimal
1,000,000	10 x 10 x 10 x 10 x 10 x10	10^6	
100,000	10 x 10 x 10 x 10 x 10	10^5	
10,000	10 x 10 x 10 x 10	10^4	
1,000	10 x 10 x 10	10^3	
100	10 x 10	10^2	
10	10	10^1	
1	1	10^0	
$\dfrac{1}{10}$	$\dfrac{1}{10}$	10^{-1}	0.1
$\dfrac{1}{100}$	$\dfrac{1}{10 \times 10}$	10^{-2}	0.01
$\dfrac{1}{1,000}$	$\dfrac{1}{10 \times 10 \times 10}$	10^{-3}	0.001
$\dfrac{1}{10,000}$	$\dfrac{1}{10 \times 10 \times 10 \times 10}$	10^{-4}	0.0001
$\dfrac{1}{100,000}$	$\dfrac{1}{10 \times 10 \times 10 \times 10 \times 10}$	10^{-5}	0.00001
$\dfrac{1}{1,000,000}$	$\dfrac{1}{10 \times 10 \times 10 \times 10 \times 10 \times 10}$	10^{-6}	0.000001

Multiply

Divide

IMSA

55

STEM Integration: Math, meet Biology! Karen Togliatti and Lindsey Herlehy
NCTM Annual Meeting: April 7, 2017

Come Scale Away
Activity 1: Powers of 10 Introduction Student Pages

What are some patterns you observed?

How does the exponential form of the number relate to its base 10 form?

What do you think the "−" means in the exponential forms of the fractions?

Problem: *How are the powers of 10 used to describe relative sizes of objects?*

Materials (per student):

- 1 – wooden clothespin
- 1 – *Sorting* card
- 1 – *Clue* card (per partner team)
- Computer with Internet access

Procedure:

View the table below and record in the box any observations that you have about the information in the table.

Metric Table

Prefix	Abbreviation	Power of 10	× "bigger" than base
giga	G	10^9	1,000,000,000
mega	M	10^6	1,000,000
kilo	k	10^3	1,000
hecto	h	10^2	100
deka	da	10^1	10
meter	m	Base 10^0	1
deci	d	10^{-1}	0.1
centi	c	10^{-2}	0.01
milli	m	10^{-3}	0.001
micro	μ	10^{-6}	0.000001
nano	n	10^{-9}	0.000000001

Discussion Questions:

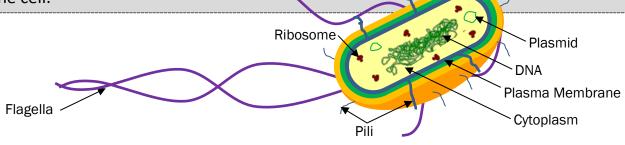1. Looking at the largest and smallest items on the list that the class made, estimate, using the Metric Table, the size of the largest and smallest items using the meter as the base unit.

    Largest item: _____

    Smallest item: _____

2. Share your estimate with a team of four students and come to a consensus on what you believe the size of each of the items would be if we were measuring using **meters** as the base unit.

    Largest item: _____

    Smallest item: _____

Now, you will participate in a sorting activity with your classmates. Following the activity, answer the questions below:

3. What item's size surprised you the most? _____

    Why? _____

    _____

4. Were some items harder to order than others? _____ Why?

    _____

    _____

5. Why are we using powers of 10 for the number line? _____

    _____

    If we were counting by "meters" would the cards for the powers of 10 be equally spaced along the number line? _____   Why or why not?

    _____

What are *E. coli* bacteria?

Background Information: *Escherichia coli,* or *E. coli,* is a type of bacteria that is engineered by many synthetic biologists to make many useful substances. *E. coli* is a single-cell organism that does not contain a nucleus like the cells in our body. Instead, the DNA that provides all of the instructions for the organism is found floating in the cytoplasm of the cell. Most of the DNA is contained in a large section that sometimes clumps together, but some DNA is found in separate, round structures known as plasmids. Investigate the cross section of the *E. coli* bacterium below and write what you believe is the function of each labeled part of the cell.

Plasma Membrane:
Flagella:
Pili:
Cytoplasm:
Ribosome:
DNA:
Plasmid:

Share your ideas with a partner. Then, share with another partner team.

Problem: *How much DNA is in an E. coli bacterium?*

Materials (per partner team):

- 1 DNA model material
- 1 *E. coli* model material
- 1 meter stick or other metric measurement tape

In the first activity, you learned that it is very difficult to imagine things at very large and very small scales. Therefore, we can make models to help us understand very large and very small objects. An *E. coli* bacterium is about 3 μm in length (not including the flagella). However, the DNA stored inside the organism is about 1.5 mm long if it was stretched out.

1. What items might we use to model both the DNA and the Plasma Membrane of the E. coli bacterium? Justify your choices.

2. With a partner, determine which is longer, the length of the *E. coli* bacteria or the length of the DNA. Then determine how many TIMES larger the longer item is than the shorter item. Show any work or calculations below:

Your teacher will give you two materials: one will represent the **DNA** in the *E. coli* cell and the other will represent the **Plasma Membrane**. How can you determine how much "DNA" you will need to place inside the "Plasma Membrane" to model the amount of DNA contained inside an E. coli bacterium? Describe your plan including any calculations in the box below.

PREDICT: Do you think you will be able to fit the DNA inside the Plasma Membrane of your model? _____ Why or why not? _____

_____

_____

3. Now, build your model of the DNA contained within an *E. coli* bacterium. Were you successful? (Circle one)

4. What are the advantages and disadvantages of using a model to simulate the amount of DNA contained in a very, very small organism?

Advantages	Disadvantages