Patterns Around Us Summer Workshop
June 26 – 27, 2019

June 26, 2019 ***ROOM: ISB Lab 264***

8:30 – 9:00 Registration. Coffee and breakfast pastries. *ISB 299M*
9:00 – 9:30 Introductory Presentation – *Jennifer Welborn and Wayne Kermenski*
Wrinkled Peas Inquiry Prelab: Weigh then soak peas
9:30 – 11:00 **Pattern: Variation in a Population** - Introduction to ADI PowerPoint –*Welborn and Kermenski*
- *Biology:* ADI investigation of color variation in a population of mealworms
- *Google Sheet* – With group's data

11:00 – 11:15 Break
11:30 – 12:30 **Pattern: Branching** -- *Welborn and Kermenski*
- *Introductory Power point*
- *Biology:* ADI villi
- *Branching Pupil Investigation handout*
- *Biology:* Root Observations—Observe home-made rhizotron/Set up radish root rhizotron
- *Physics:* Making a Heleshaw Cell
- *Biology:* Observe Slime mold/ Set up slime mold

12:30 – 1:00 **Lunch**: bag lunches provided. *ISB 399M*

1:00 – 2:30 **Pattern: Wrinkling**
- Wrinkling in nano-scale sheets Lab – *Professor Narayanan Menon*

2:30 – 3:30 Data analysis
3:30 – 4:00 Debrief the day

June 27, 2019

8:30 – 9:00 Coffee + breakfast pastries. *ISB 299M*
9:00-10:30 **Pattern: Buckling**
- *Biology*: ADI Tree Investigation—description
- Buckling Presentation -- *Professor Benny Davidovitch*

10:30-10:45 Break
10:45-12:30 **Pattern: Wrinkling** -- *Welborn and Kermenski*
- *Biology:* Wrinkled Peas? Pupil Inquiry Lab Handout
    - Human Saliva activity
    - Osmosis and Dialysis Tubing Activity
    - Analyzing Dry and Imbibed weights of wrinkled and smooth pea seeds - google spreadsheet
    - Inquiry Lab—Putting it All Together, What makes wrinkled peas?

12:30-1:00 **Lunch.** *ISB 399M*

1:00-2:15 **Pattern: Wrinkling** -- *Welborn and Kermenski*
- Wrinkling power point
- *Biology/Physics/Technology*: Much Ado About Wrinkling Pupil Activity

2:30-3:30 Debrief + Curriculum brainstorming

Wrinkled Peas?

Introduction

Brother Gregor Mendel chose pea plants as his model partially for their flower shape, which helps prevent cross-pollination. One of the characteristics he focused on was the shape of the pea seed. Some pea seeds are wrinkled, and some pea seeds are smooth in their appearance. When Mendel crossed plants grown from round (or smooth) pea seeds with plants grown from wrinkled pea seeds, the first generation pea seeds were all round and smooth. He called it the F1 generation. When he crossed two offspring from the first generation, the second generation (F2) produced an almost perfect 3:1 phenotypic ratio. Three-fourths of the second generation produced round seeds, and one-fourth produced wrinkled seeds. Combined with his studies of six other traits, Mendel concluded that pea plant traits were governed by two determiners (we now call these genes). One of the determiners was contributed by the pollen, the other by the pea-plant ovule. His further conclusion, important to this learning experience, was that smooth pea seed factors are dominant to factors for wrinkled pea seeds. Mendel's findings were made before knowledge of cell structure. He knew nothing about chromosomes and genes. He was not aware of the diploid state found in most eukaryotic cells. But he was a mathematician, and he did deduce the probability that two determiners control hereditary traits in pea plants. However, why are some peas wrinkled? In this investigation, we will explore the scientific principles that lead to peas becoming wrinkled.

This lab experience is separated into four investigative segments:

1. Human saliva and enzymes
2. Osmosis and Dialysis Tubing
3. Analyzing dry and imbibed weights of wrinkled and smooth pea seeds
4. Putting it All Together, What makes Wrinkled Peas?

<u>NGSS Science Standards:</u>

HS-LS1-6. Construct and revise an explanation based on evidence for how carbon, hydrogen, and oxygen from sugar molecules may combine with other elements to form amino acids and/or other large carbon-based molecules.

HS-LS1-7. Use a model to illustrate that cellular respiration is a chemical process whereby the bonds of food molecules and oxygen molecules are broken and the bonds in new compounds are formed resulting in a net transfer of energy.

Human Saliva and Enzymes

LEARNING OBJECTIVE:

- Be able to identify the importance of enzymes as it relates to digesting food consumers eat.
- Explain the effect enzymes have on long chain macromolecules.
- Recognize the importance of saliva in one's digestive tract.
- Differentiate between a monosaccharide, disaccharide and polysaccharide.

INTRODUCTION:

In this laboratory experiment, we will be investigating the ability of enzymes to break down starch. There will be five test tubes with different mixtures in them. Using the information we have already discussed, predict whether the test tube already has monosaccharides or polysaccharides, and if the enzyme will break down polysaccharides to monosaccharides. Before you start, refresh yourself with enzymes and whether honey and starch are mono or polysaccharides. You will be provided with Benedict's solution, which can detect for the present of monosaccharides, but not polysaccharides. The Benedict's solution will turn a different color when there are monosaccharides in a solution.

PROBLEM: How does your body break down long polysaccharides (starch) and disaccharides (sugar), to monosaccharides in order to use them for energy?

HYPOTHESIS: Predict whether you will see a color change representing a presence of glucose in each of the test tubes.

Test tube 1: Honey Mixture (monosaccharide)
Prediction:

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Test tube 2: Sugar Mixture (disaccharide)
Prediction:

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Test tube 3: Corn Starch Mixture (polysaccharide)
Prediction:

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Test tube 4: Sugar Mixture (disaccharide) with saliva
Prediction:
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Test tube 5: Corn Starch mixture (polysaccharide) with saliva
Prediction:
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MATERIALS:
5 test tubes
One 250 ml beaker in order to carry test tubes
10 ml graduated cylinder
Dixie cup
Water dropper
Benedict's Solution
Thermometer
Warm water bath (37^{O}C)

PROCEDURE:
1. Label each test tube with a 1,2,3, 4 and 5.
2. In test tube 1, add 5 ml of honey mixture
3. In test tube 2, add 5 ml of sugar mixture
4. In test tube 3, add 5 ml of starch mixture
5. In test tube 4, add 5 ml sugar mixture and saliva
6. In test tube 5, add 5 ml starch mixture and saliva
7. Put all five test tubes in a warm bath at 37 degrees C for five minutes.
8. After five minutes, add 20 drops of Benedict's solution to each test tube.
9. Place test tubes in hot (90-100^{o}C) water bath for a few minutes
10. A color change will represent a positive result.

DATA:

Test Tube	Result (positive or negative)
1	
2	
3	
4	
5	

CONCLUSION: (What happened in each of the tests tubes and was your hypothesis right?)

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Lab Questions:

1. What can you say about saliva and the presence of enzymes and digesting food? Does chewing your food help with digestion? Why?

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2. What kind of organic molecule is an enzyme? What does it mean for organic molecule become denatured?

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3. Convert 37 degree C to F. Why do you think the water bath was 37 degrees Celsius? Do you think the temperature of the water is an important variable? Why?

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Investigation with Dialysis Tubing

LEARNING OBJECTIVE:

- Explain osmosis and diffusion and why it occurs.
- Identify the directional flow of water through a semipermeable membrane.

INTRODUCTION:

Videos:

http://highered.mcgraw-hill.com/sites/0072495855/student_view0/chapter2/animation__how_osmosis_works.html

MATERIALS:

- Dialysis Tubing (3 – 12 cm strips)
- White sugar from the grocery store
- Cornstarch from the grocery store
- 10 or 50 ml graduated cylinder
- Scissors
- Two Dixie cups
- 3 - 250 ml beakers or large cups
- Paper towel
- Digital balance
- Thread
- Water

PROCEDURE:

1. Using a balance, weigh out 5 grams of sugar and put into a paper cup. Add 10 ml of water. Set aside.
2. Repeat step 1 using cornstarch.
3. Cut three 12 cm sections of dialysis tubing.
4. Immerse both sections in water for 30-45 seconds.
5. Take the sections out of the water and open them into tubes by rolling between the thumb and index finger.
6. With a piece of thread, securely tie off one end of one of the tubes (leaving about .5 cm between the end of the tubing and the thread.)
7. Pour the sugar solution into the open end. Once the solution is inside, use another piece of thread to tie off the open end.
8. Repeat steps 6 and with the starch solution and tap water.
9. Put the sugar solution/dialysis pouch on a balance. Record the mass in grams in the data table.

10. Repeat Step 9 using the starch solution/dialysis pouch **<u>and</u>** tap water/dialysis pouch.
11. Put all three of the pouches in I a beaker with 200 ml of water making sure the pouches are submerged under the water.
12. Wait for 15 minutes.
13. Remove each pouch and dry the outside thoroughly with a paper towel.
14. Put each pouch onto a balance again and record the final mass (after being in water).

DATA:

Contents in dialysis pouch	Mass Before Putting in Water (dry weight)	Mass after Putting in Water (wet weight)	Weight Difference	% increase= Weight difference/ Dry weight
Tap H_2O				
Sugar				
Corn Starch				

RESULTS:

1. Which dialysis pouch gained more mass or more water?

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CONCLUSION:

2. What pouch was your control?

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3. What do you suppose caused the sugar pouch to gain mass? Please answer this question by drawing a picture of the two different dialysis bags and explaining osmosis (the movement of water and attraction of water to different compounds) caused by starch and sugar. View this video for help: http://highered.mcgraw-hill.com/sites/0072495855/student_view0/chapter2/animation__how_osmosis_works.html This can be found on the google site under links.

Sugar Pouch

Explanation:

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Starch Pouch

Explanation:

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Analyzing dry and imbibed weights of wrinkled and smooth pea seeds

INTRODUCTION:

Seeds often contain starch, which is composed of thousands of glucose molecules joined end to end in long chains. Starch is a good way to store carbohydrate because it is less reactive than sugars, basically insoluble, and does not attract water by osmosis. Because sugars, like glucose and sucrose, attract water by osmosis, a fresh seed with a lot of sugars has a higher water content. When it dries out, it loses more water and wrinkles. Sweet corn (Zea mays) is a seed with higher sugar content, hence the sweet taste. Smooth corn seeds are higher in starch so would not be eaten fresh like sweet corn. Similarly, smooth peas (Pisum sativum) are less sweet and are used in soups and were once even used to make flour. Wrinkled peas are sweeter so are eaten whole as a vegetable. The purpose of a seed is to store food, which gives energy to the baby plant to help it grow until it can make its own sugar by photosynthesis. One of the sources of energy stored in the seed is a simple sugar, called glucose. Another source of energy for the baby plant is starch. Starch is made up of glucose molecules put together. In this investigation, you will see how sugar and starch relate to water flow. Observe the picture to the right, can you identify wrinkled and smooth peas?

PURPOSE:

Is there a difference between how much water wrinkled and smooth peas can absorb?

MATERIALS:

10 smooth peas
10 wrinkled peas
2 small beakers (or waxed cups)
digital balance
paper towels
water

PROCEDURE:

1. Weigh ten smooth pea seeds and place them in a beaker or waxed paper cup labeled “S” for “smooth.” Record your result under dry weight.
2. Weight ten wrinkled peas placed in a beaker or waxed paper cup labeled “W” for “wrinkled.” Record your result under dry weight.
3. Add 100 ml of water to a 250 ml beaker and add both samples to cover peas completely.
4. Allow one day for peas to absorb water
5. **NEXT DAY:** Fish out imbibed peas. Place the peas on separate paper towels and blot them dry. Reweigh each sample and record the weight data under “weight wet” in your table. Calculate the percent of weight increase for each pea variety and record the data.
6. Complete the data table.

DATA:

Pea variety	Dry weight	Wet weight	% increase
Wrinkled			
Smooth			

RESULTS:

Please show your work for finding percent increase

Wrinkled:	Smooth:

Percent Increase Example:

CONCLUSION:

1. What pea variety absorbed more water?

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2. Looking back at your dialysis experiment, why does one pea absorb more water than the other?

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3. If you were going to grow peas in your garden, which ones would you grow and why?

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Putting it All Together, What makes Wrinkled Peas?

INTRODUCTION: In this final experiment, you will need to determine which peas lack the enzyme that convert sugar within the pea to starch. What makes this challenging is you will not be able to tell by how they look, because the peas will be soaked overnight and they will look the same. You will need to develop a procedure that will help you decide which pea is wrinkled or smooth. Some general materials will be provided, but if you want additional materials please ask. *This experiment will be formally written up.*

PURPOSE: Which peas lack the enzyme that converts the sugar within the pea to starch and are wrinkled and which ones have the enzyme and are round?

HYPOTHESIS:

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MATERIALS

- 4 peas (2 from beaker 1 and 2 from beaker 2))
- test tubes (labeled beaker 1 and beaker 2)
- 250 ml Beaker
- warm water bath
- Digital balance
- water, H2O
- Benedict's solution
- Pipettes

PROCEDURE:

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DATA TABLE:

RESULTS:

CONCLUSION:

Additional question: Take two peas from each sample and allow them to dry out. Make sure you indicate which are from the smooth group and which are from the wrinkled group. Allow one to two days for the peas to dry.

Did your results match up with what was observed when you dried out a pea from each beaker?

Name: ________________________________ *Assignment: ADI Pattern investigations*

Analyzing patterns of variation in populations.

NGSS:

- MS-LS4-4. Construct an explanation based on evidence that describes how genetic variations of traits in a population increase some individuals' probability of surviving and reproducing in a specific environment.
- HS-LS3-3. Apply concepts of statistics and probability to explain the variation and distribution of expressed traits in a population.

Introduction:

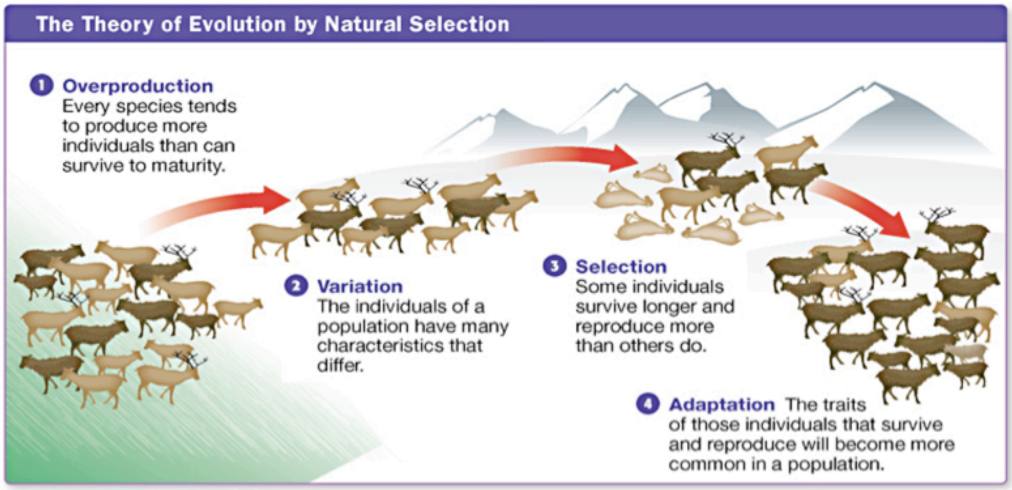
Means and Variation in a Population

A population of organisms almost never consists of individuals that are all exactly alike. For example, you have probably noticed quite a bit of variation in the size, shape, color and firmness of apples in a grocery store bin. Nevertheless, if you were to describe apples, you might describe one that had a size, shape, color and firmness that were not particularly extreme but which you felt best represented apples in general. Such an apple would be an average, or mean, with respect to the particular traits you used to describe it. In biology, the mean value is useful for a number of reasons. It helps naturalists describing and classify organisms. Second, the mean can be used for comparing populations or samples.

However, despite our tendency to think about average organisms, for some traits there remain considerable variation among individuals in a population and this variation is very important to the evolution of species. Darwin was the first to understand the importance of such variation in organisms that is an important component of natural selection.

The mean and variation of a population are easily seen by graphing the number of individuals that have a trait of a given value. In this experiment, we will investigate color variation found in a mealworm population using ADI.

Name: ___________________________________ *Assignment: ADI Pattern investigations*



Pre-lab question.

In the natural selection diagram presented, identify why it is beneficial for a population to have variation in traits.

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Purpose:

Using ADI, we will examine whether there is variation in the color of a small population of mealworms.

Materials:

- Camera
- 20 mealworms
- Area with good lighting in order to take good pictures
- Computer with ADI program
- ADI Manual

Name: ________________________________ *Assignment: ADI Pattern investigations*

Procedure for taking a picture of a mealworm population:

1. Designate an area with good lighting in order to take pictures of you mealworm population.
2. Place 20 mealworms in a petri dish.
3. Take a picture 30 cm from the mealworms. Make sure the picture is clear.
4. Use ADI program to assess the average color for each mealworm found in your population. In order to accomplish this, follow the instructions outlined in the ADI manual. Record the average color for each mealworm in the table below.

Data:

Mealworm	Average Color
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	

Mealworm	Average Color
11	
12	
13	
14	
15	
16	
17	
18	
19	
20	

Results:

Identify the range for the average color value for your population. Recall range can be calculated by subtracting the smallest value from the largest value.

Once the range has been identified, create interval values for the data that will best represent the pattern of variation. For example, if the range was 20, a good interval may be 4; 30-34, 34-38, 38-42, 42-46, and 46-50. However, you will have to use your judgment on this one.

Conclusion:

<u>Examining the results from your graph.</u>

1. Did you find color variation in the mealworm population?
2. How does variation of a trait within a population relate to the theory of natural selection? Please use the mealworm population as an example.

Name: ________________________________ *Assignment: ADI Pattern investigations*

Branching pattern found in the small intestines?

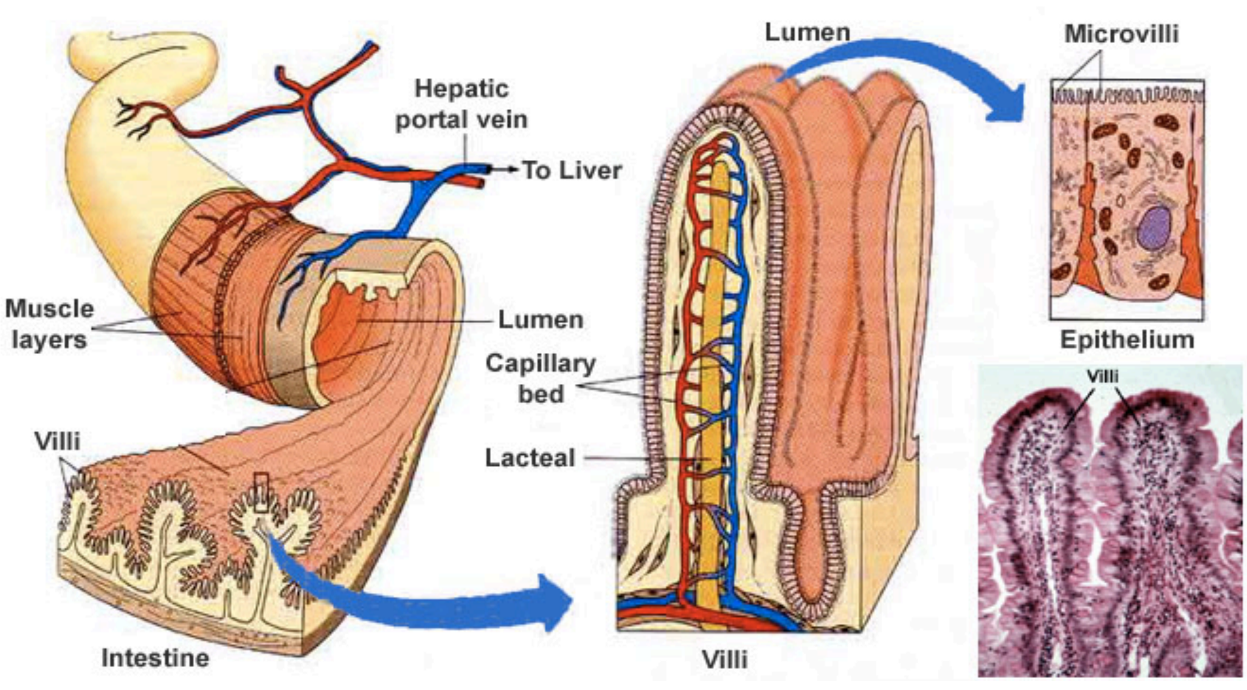
NGSS

MS-LS1-3. Use argument supported by evidence for how the body is a system of interacting subsystems composed of groups of cells.

HS-LS1-2. Develop and use a model to illustrate the hierarchical organization of interacting systems that provide specific functions within multicellular organisms.

Introduction:

The main function of the digestive track is to absorb nutrients from the food organisms eat. One mechanism by which the digestive system accomplishes this is by increasing the surface area of the intestines. Lets use a sponge as an example. If you spilt milk on the floor, the best way would be to get as much surface area of the sponge in contact with the milk. In doing so, you will be able to soak up the milk more efficiently. How your digestive tract improves its surface area is by folding the outer surface many times over similar to a wave pattern. These folds are referred to as villi and microvilli. Please refer to the picture below.



Purpose:

In this investigation, we will use digital images and ADI to measure the increased surface area created by villi located in the small intestines.

Name: ________________________________ *Assignment: ADI Pattern investigations*

Materials:

- Computer with ADI
- Real picture of villi tissue

Procedure:

1. Download a real picture of villi from the google images and save it to your desktop.
2. Refer to the ADI manual for importing and measuring images.
3. Using the measuring tool, measure the distance of the villi image from one end to the other.
4. Using the measuring tool, measure the surface length of the villi.

Data:

Length of the image from one side to the other: _______

Length of the villi surface: ______

Results:

By how many times more do villi increase the surface area of the small intestines?

Conclusion:

1. What effect do you think microvilli have on the surface area of your small intestines?
2. Look up how much surface area of an average person's small intestine. Before you do that, what do you think the area is?___________________ Where you close? ______________
3. Review: What is the main purpose of the digestive trait? In a few sentences, explain how our body has evolved to make this function possible?

Name: ________________________________ *Assignment: ADI Pattern investigations*

Is tree height determined by the physical principle of buckling?

NGSS:

- MS-LS4-6. Use mathematical representations to support explanations of how natural selection may lead to increases and decreases of specific traits in populations over time.
- HS-LS3-3. Apply concepts of statistics and probability to explain the variation and distribution of expressed traits in a population.
- HS-LS4-3. Apply concepts of statistics and probability to support explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait.

Introduction:

Buckling Strength

The maximum height of a vertical column can be determined by Young's modulus of the material and the radius. This can be calculated by the formula below:

$$I_{cr} = cr^{2/3}$$

I = height of the column
c = constant of a material
r = radius of the column

Buckling Strength and Structural Design in Nature

It is a competitive advantage for trees to grow tall and capture as much sunlight as possible. But, is there a limit to how tall a tree can grow? What determines how tall a tree can grow?

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Following the principles of natural selection, trees that have the trait for tallness but do not have the ability to handle the force created by this trait could buckle, die and not pass on their tallness trait to the next generation. Therefore, there may be a relationship between tallness and trunk diameter for trees. In this Investigation, we will examine whether there is a limit to how tall a tree can grow given its trunk diameter.

Using analyzing digital images (ADI) one can take a picture of a tree and measure various tree dimensions. In order to accomplish this, the picture needs to have a known length within the picture as a reference and the picture should be taken on relatively flat ground.

Name: ________________________________ *Assignment: ADI Pattern investigations*

Purpose:

In this investigation, we will look to identify whether trees have evolved to follow the physical principles of buckling.

Materials:

- Camera
- Computer with ADI program downloaded
- 2 Meter Stick for reference
- DBH stick (1.37 m)
- DBH Tape Measurer

Procedure for measuring the height of a tree with a camera:

1. Find a tree that can be photographed on flat ground.
2. Keep the camera lens parallel to the object(s) that will be measured.
3. Fill the picture frame with the object of interest.
4. Put a scale of known length in the same plane as the picture. We will use the DBH stick.
5. Take 3 pictures in order to maximize the chance that at least one of the photographs will be in sharp focus.

Once three pictures of your tree have been taken, please follow the directions for using the ADI program to get the height and truck diameter of your tree.

Data:

Height of your tree: _______ meters

Diameter of your tree: ______ meters

Please share your results with the class and record the class results in the table below.

Group	Height of tree (meters)	Diameter of tree (meters)	Radius of tree (meters)	$I_{cr} = cr^{2/3}$ solve for c

Name: ________________________________ *Assignment: ADI Pattern investigations*

Results:

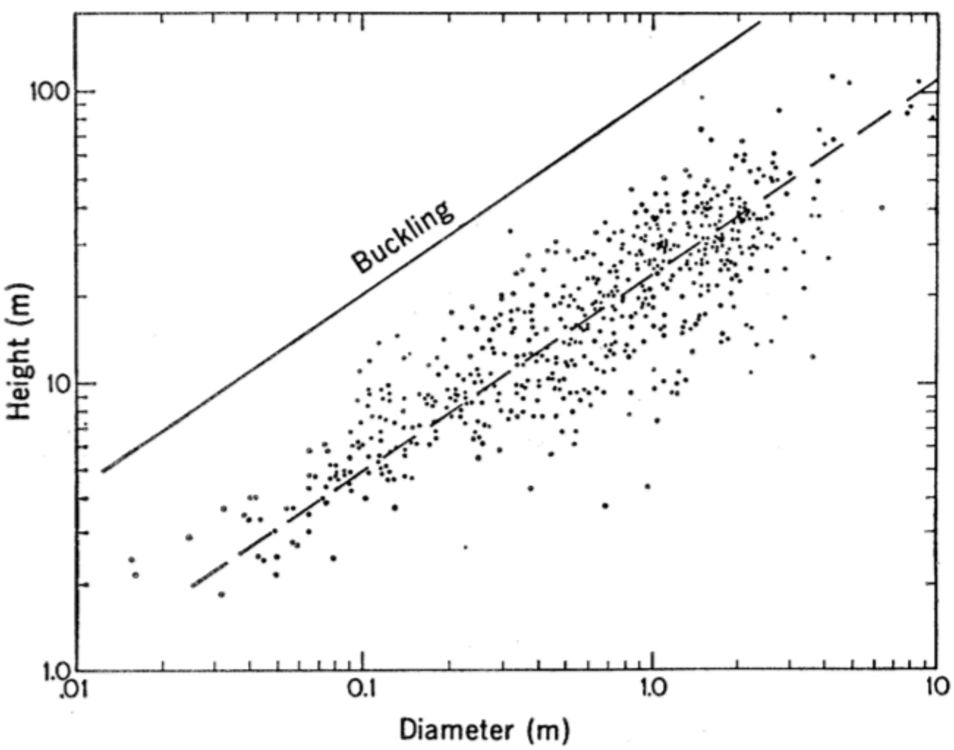
In the final column of the data table, please solve for “c” using each group’s measurements. Please attach a separate piece of paper showing your calculations.

Conclusion:

1. Was the constant “c” consistent for each tree? Why? Why not?

2. Research has shown (MCMAHON, T.A. 1973. Size and shape in biology. Science 179: 1201-1204.) that c = 34.9 $m^{1/3}$. Was the mean for the class result similar to the previous result?

McMahon’s data on tree buckling is shown below.



3. Do you think trees abide by physical principles in regards to their height?

4. Could the correlation between height and trunk diameter be an evolutionary adaptation?

Patterns Around Us: Branching in Nature

Teacher Resource Page

Part A: Introduction to Branching

Massachusetts Frameworks Alignment—The Nature of Science

- Overall, the key criterion of science is that it provide a clear, rational, and succinct account of a pattern in nature. This account must be based on data gathering and analysis and other evidence obtained through direct observations or experiments, reflect inferences that are broadly shared and communicated, and be accompanied by a model that offers a naturalistic explanation expressed in conceptual, mathematical, and/or mechanical terms.

Materials: None

Background Readings About Branching in Slime Molds and Leaf Venation as a model for efficient road and railway systems

https://www.scientificamerican.com/article/brainless-slime-molds/

http://scienceblogs.com/notrocketscience/2010/01/21/slime-mould-attacks-simulates-tokyo-rail-network/

https://culturingscience.wordpress.com/2010/02/11/nature-inspired-network-design-recent-studies-in-slime-mold-and-leaf-veins/

http://www.cbc.ca/news/technology/slime-mould-mimics-tokyo-s-railway-1.972463

Part B: Regular Branching Patterns

Science Frameworks Alignment:

- Overall, the key criterion of science is that it provide a clear, rational, and succinct account of a pattern in nature. This account must be based on data gathering and analysis and other evidence obtained through direct observations or experiments, reflect inferences that are broadly shared and communicated, and be accompanied by a model that offers a naturalistic explanation expressed in conceptual, mathematical, and/or mechanical terms.

- Identify the general functions of the major systems of the human body (digestion, respiration, reproduction, circulation, excretion, protection from disease, and movement, control, and coordination) and describe ways that these systems interact with each other

Math Frameworks Alignment

- Write expressions and equations that correspond to given situations
- Understand the connections between proportional relationships, lines, and linear equations.

Materials: None

Part C: Viscous Branching

Science Frameworks Alignment:

Differentiate between mixtures and pure substances

Use and refine scientific models that simulate physical processes or phenomena.

Materials: Hele Shaw Cell, glycerin, food coloring, syringe (without needle) or eyedropper, water, oil, cups, 25 ml graduated cylinders

How to make a Hele Shaw Cell

1. Obtain a CD case. It is best to have two clear sides to the cell. If the CD case has only one side that is clear, use two CD cases.
2. Disassemble the CD cases. Drill a hole in one of the covers.
3. When making the cell, separate the two plastic sides with thin pieces of glass or plastic such as cover slips. The plastic sides should be separated only by the cover slips. This allows a material to be injected into the cell.

Part D: Branching in Roots

Frameworks Alignment

- Inquiry, experimentation, and design should not be taught or tested as separate, standalone skills. Rather, opportunities for inquiry, experimentation, and design should arise within a well-planned curriculum. Instruction and assessment should include examples drawn from life science, physical science, earth and space science, and technology/engineering standards.
- Asking questions and pursuing answers are keys to learning. Inquiry, experimentation, and design should not be taught or tested as separate, standalone skills. Rather, opportunities for inquiry, experimentation, and design should arise within a well-planned curriculum.
- Identify the structures in plants (leaves, roots, flowers, stem, bark, wood) that are responsible for food production, support, water transport, reproduction, growth, and protection.

- Recognize plant behaviors, such as the way seedlings' stems grow toward light and their roots grow downward in response to gravity. Recognize that many plants and animals can survive harsh environments because of seasonal behaviors
- Recognize that every organism requires a set of instructions that specifies its traits. These instructions are stored in the organism's chromosomes. Heredity is the passage of these instructions from one generation to another.

Materials: two different kinds of seeds which have similar germination times (corn and peas for example); cups, plastic wrap, 3 different kinds of growing media, cardboard, plastic sandwich bags or quart bags, binder clips

How to Make a Rhizometer

1. Put soil or other growing media into a plastic sandwich or quart bag. Flatten the bag and plant a seed near the top of the soil. Do not completely close the top of the bag. Roots need air!
2. Put the bag in between two pieces of cardboard and use binder clips to keep the cardboard sides closed. Prop up or vertically suspend the rhizometers so the roots grow down.
3. Open up the rhizometer periodically to view root growth.

Readings About Rhizometers

hortsci.ashspublications.org/content/50/2/288.full.pdf

https://www.amerinursery.com/growing/keeping-an-eye-on-root-development/

https://ashs.confex.com/ashs/2015/webprogramarchives/Paper21758.htm

archives.ashs.org/abstracts/2013/abstracts13/abstract_id_15841.html

agris.fao.org/agris-search/search.do?recordID=CA19810635817

Reading about Scaling in Biological Systems

George Johnson, in his New York Times article entitled Of Mice And Elephants: A Matter Of Scale , states:

"scaling emerges from the geometrical properties of the internal networks animals and plants use to distribute nutrients ". Scaling laws arise from a network transport system where (1) a space filling hierarchical branching pattern is required (2) the final branch of the network (where nutrients are exchanged) is a size-invariant unit and (3) organisms have evolved so that the energy required to sustain them is minimized. These networks are fractal -- each small part is a copy of the whole. Scaling laws result from the interplay between the physical and geometric constraints implicit in these three principles.

There is a correlation between the power law model and much of the processes and shapes that define patterns in nature. It is a consistency that is driven by a both interdependency and feedback.

The scale invariant characteristics that are so prevalent in patterns in nature apparently serve to cope with environmental factors that are not scale invariant. These non-scalable factors (those that do not depend on body size, shape, magnification, or symmetry) include physical and chemical constants and water – the universal solvent for life which has non-scalable properties.

http://www.patternsinnature.org/pin_essay_01.html

"… biological systems obey a host of remarkably simple and systematic empirical scaling laws which relate how organismal features change with size over many orders of magnitude. These include fundamental quantities like metabolic rate (the rate at which energy must be supplied to sustain an organism) , time scales (like lifespan and heart rate) and sizes (such as the length of the aorta or the height of a tree trunk). It is remarkable that all of these can be expressed as power law relationships with exponents that are simple multiples of ¼ (e.g. ¼, ¾, 3/8) . They appear to be valid for all forms of life whether it be mammalian, avian, reptilian, unicellular or plant-like. These "laws" are clearly telling us something important about the way life is organized and the constraints under which life has evolved. " West proposes that scaling laws are the unifying feature of patterns in nature.

The Origin of Universal Scaling Laws in Biology

www.darkcoding.net/research/gbwscl99.pdf

Patterns Around Us: Branching In Nature Pupil Page

Objectives

Be able to:

- Explain how and why branching patterns occur in nature
- Use RAPT (recognize, analyze, predict and test) to recognize a regular branching pattern, develop a rule for subsequent branching levels, and test the rule.
- Determine if the branching pattern is linear or exponential
- Design and conduct an experiment involving spontaneous viscous branching
- Design and conduct an experiment involving branching in roots

Part A: Introduction to Branching

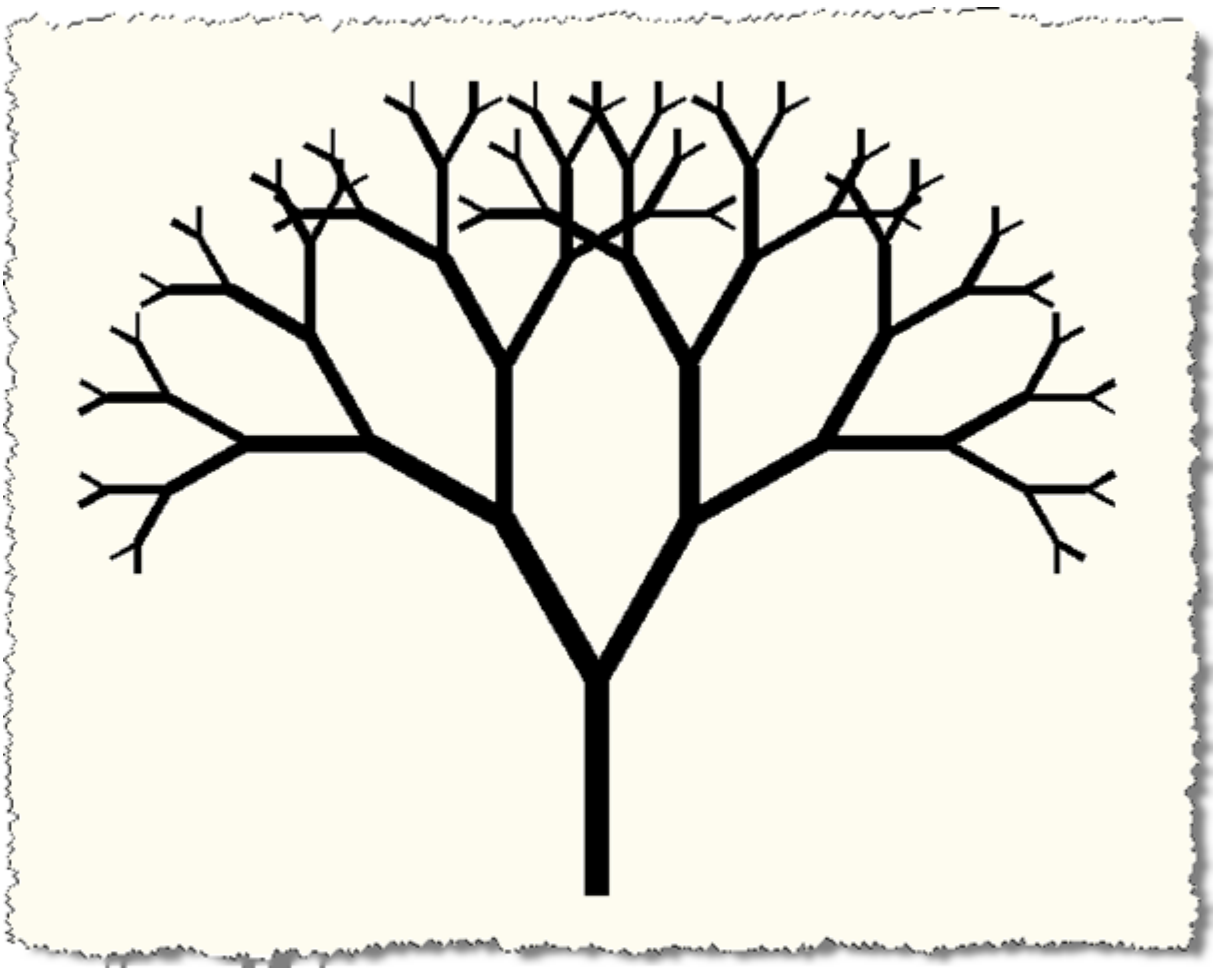
Patterns are the result of a balance of forces. Branching patterns in nature show the flow of materials and/or energy. Branching is an efficient way to distribute or collect materials or energy.

Turn and talk: talk to your neighbor and brainstorm where you see branching patterns in nature. For each observation, record what kinds of materials or energy are being distributed or collected efficiently.

Observation of Where Branching Pattern Occurs in Nature	**What materials or forms of energy are being distributed or collected efficiently?**
Example: circulatory system—arteries, veins, capillaries	Oxygen, carbon dioxide, water, nutrients

Part B: Regular Branching Patterns

There are different kinds of branching patterns. Some branching patterns are fractal in nature and can be quantified. The branching diagram below has 7 orders. An order is a level of branching. The first order would be the main branch.



1. Complete the table below.
2. Use the data in the table to predict the number of branches at order number 8.
3. Test your prediction by drawing the next level of branches.

Order Number	Number of branches
1	1
2	2
3	4
4	
5	
6	
7	
8	

4. Can you come up with a rule for determining the number of branches for each order?

5. Graph the data: The x-axis is order number and the Y-axis is number of branches. What do you notice? Is the relationship between order number and branches linear or exponential?

Extension/Challenge

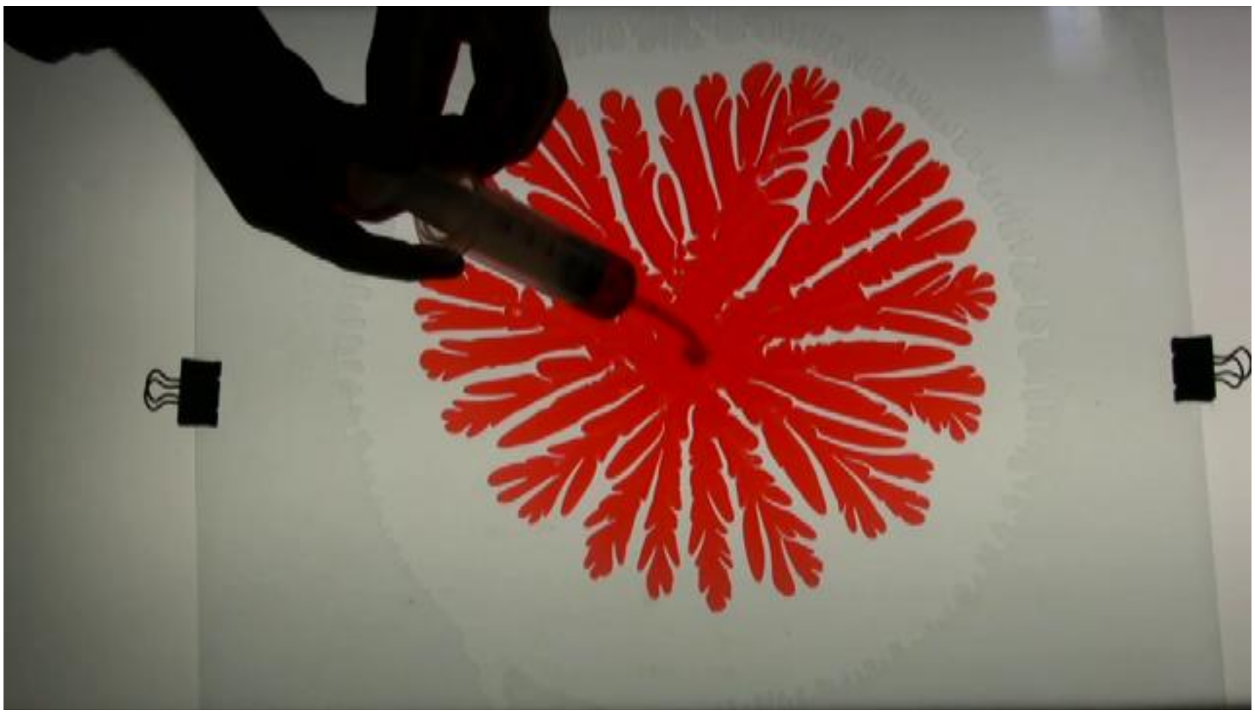
Challenge #1: Have students plot log (number of branches) vs order number and see the result.
Challenge #2: Ask students to draw another kind of fractal branching pattern and develop a rule for it.
Challenge #3: Ask students to go outside and observe branching patterns on trees. See if they can come up with a way to quantify the pattern and predict where the next set of branches will occur.

Part C: Investigating the Physics of One Kind of Branching—Viscous Branching with a Hele Shaw Cell

Research Question: What is the effect of forcing an interaction between two immiscible fluids?

In this activity, you will observe that when one substance of a certain viscosity is pushed into another substance of a different viscosity, a branching pattern results.

1. Construct a Hele Shaw cell using a CD case.
2. Put 20 ml of glycerin in the center of the bottom half of the cell. Put two plastic cover slips on the edges of the bottom half.
3. Put the top half on. Wipe off the excess glycerin that comes up through the hole.
4. Inject 3 ml of colored water at a slow rate.
5. Observe the effect. Take a picture if possible.
6. Clean off the Hele Shaw Cell
7. Repeat steps 2-6 but increase the rate at which the colored water is injected.
8. Clean off the cell and repeat the above steps but put the food coloring in the glycerin and inject 3 ml of air instead.
9. If time, repeat the steps above using baby oil rather than glycerin. What do you notice?
10. Talk to your neighbor: Where do we see this phenomenon happen in nature? (Where a material of one viscosity infiltrates a material of a different viscosity, creating a branching pattern)?



Extension

Test the Hele Shaw cell with various fluids of various viscosities. Predict in advance what patterns will emerge. Test your prediction.

Check out this website: http://n-e-r-v-o-u-s.com/blog/?tag=hele-shaw-cell

Part D: Branching in Roots—A Guided Inquiry

Research Questions: What is the effect of kind of growing medium and kind of seed on root branching?

Roots have various functions in plants: provide an anchor for the plant; absorb water from the soil for photosynthesis; absorb minerals from the soil (nitrogen, phosphorous) to make proteins; absorb oxygen from the soil for cellular respiration. Branching is an efficient way of collecting or distributing materials for the plant because branching increases surface area. In this investigation, you will observe the effect of growing medium and kind of seed on root branching.

Create Rhizometers

1. Put equal masses of 2 different kinds of growing media into 2 different quart-sized bags. Add the same volume of water to each bag. There should be enough water so the soil is moist but not too wet.
2. Plant a pea (or other choice of seed) seed in each of the bags at the same depth. Peas are dicots.
3. Repeat steps 1 and 2 using corn seeds. Corn is a monocot.
4. Put each of the plastic bags between 2 pieces of cardboard or foam board. Use binder clips to keep the cardboard pieces in place during the experiment and to keep the bag flat and thin (like an ant farm) so that roots can be observed when opened. The cardboard also reduces exposure to light.
5. Observe the rooting patterns of both kinds of plants over time: 3 days, 5 days, 10 days, 15 days, etc.

Questions

1. Does the medium in which a seed is planted affect the amount of branching of the roots?
2. What is the effect of changing the physical conditions of root development on root growth and root branching?
3. Are there differences in root branching patterns between the species of plants that you tested?
4. How and why does root branching affect the health of the plant?
5. How is root growth and root branching related to the flow of plant hormones such as auxin?

Extension to Lab

1. Repeat the experiment with a different kind of plant seed. What do you notice?
2. Repeat the experiment using different amounts of water. What do you notice?
3. Is there are relationship between the amount of branching and the health of the plant?
4. How much is root branching genetic and how much is environmental?
5. Investigate how and why roots grow and how and why branching occurs. What are the important hormones related to root branching.
6. How is the distribution of root hormones related to viscous branching?

7. Investigate how and why apical dominance occurs.   How and why does cutting the tip off a branch increase branching below it?
8. Is there a numerical relationship between the number of branches and the number of roots?

Branching Extension
Research the application of fractal branching in tissue regeneration.   Use the following website as a place to start your research.
http://www.fractal.org/Life-Science-Technology/Publications/Fractals-support-growing-organs.htm

Part E: Slime Mold Branching and Network Efficiencies---Just a Few of the Many Fascinating Readings

http://www.archaeology.org/issues/182-1507/trenches/3365-trenches-roman-roads-slime-mold

http://news.nationalgeographic.com/news/2013/01/130110-cheaters-slime-mold-science-weird/

Slime Mold Culture Kits can be purchased from Carolina Biological Supply Company.

Wrinkling of a floating sheet - Experiment

Teachers' programme on Patterns in Nature

Context

You've already heard about wrinkling in various contexts. Today we'll be looking at an exceptionally clean wrinkle pattern based on a recent research experiment conducted at UMass. This experiment is relatively simple, and can be conducted in your school, with a little practice. If you liked the pattern you create today, please contact us for materials for you to use at school.

Goals

The objective of today's work will be to generate wrinkle patterns on very thin polymer films using the forces generated by the surface tension of a water drop. You'll do a few sizes of water drop and we'll give you a couple of thicknesses of film. Digital images of the pattern will allow us to make observations of the number and size of the wrinkles generated. We will try to develop an understanding of the dependence of the pattern on the materials used and the forces applied.

Materials

Slides with film; Plastic rulers; Plastic or glass dishes; Clean water; Syringes; Cell phone Camera; Paper Tissue

Procedure

<u>Making the film</u>

This part of the action happens off-stage but it's perhaps of interest to you. We provide you with ultrathin sheets coated on to glass microscope slides. The sheets are made of a very common polymer – polystyrene. The sheets are made by a process called spin-coating, which is extremely common in the industries that make electronic chips[1]. Spin-coating is very similar to applying a coat of varnish to a table-top or to a finger nail. You take the polymer in powder form and dissolve it in a solvent. A drop of this solution is put on a microscope slide, and spun around at a high rotation rate so that it spreads out uniformly. The solvent then evaporates leaving a thin layer of the solid film.

Handle the slides by their edges and don't put your fingers on them. The films you're given have a thickness in the range of 50 to 200 nanometres – this is about a thousand times thinner than a typical human hair.

<u>Floating the film and making wrinkle patterns</u>

The next task is to get the polymer film off the microscope slide on to the surface of water. Use a razor blade to cut an approximately square shape on the film – you should be able to get about three such pieces off the slide. Then, holding the slide by the edge, insert it into the water surface. The square piece of film should peel off and float on the water. (Question: *Why doesn't it sink inside even though the plastic is denser than water*).

[1] The first part of making a chip is to lay down a thin layer of polymer by spin-coating. Then they carve trenches using light (or electron beams) in the polymer where they would like to lay down metal or semiconductor. Once this is done, they wash away the rest of the polymer. The whole process is called photolithography.

Look at the colours from light reflected off the film. (Question: *Why do you see colours? The sheet is thinner than the wavelength of light).* You should be at least a little surprised that you can see something from the nano world with your eyes!

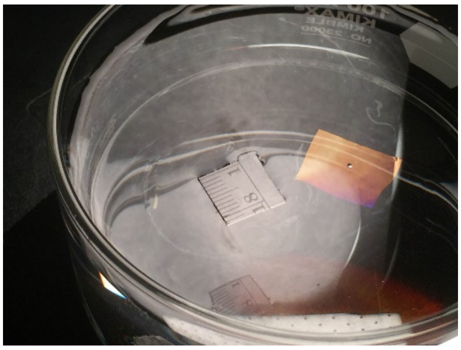
Creating a wrinkle pattern

Now take a syringe filled with water – be careful not to poke yourself with the metal tip – and place the smallest drop of water that you can near the centre of the film. Don't squeeze out a large drop of water. If you do so, use the edge of a tissue to absorb it. We suggest that you practice ejecting a water drop on the table top first. Try not to do this with a splash, by bringing the needle as close to the surface as possible. If you do this successfully, you should have a round drop, decorated with a starburst of uniform wrinkles radiating out from the edge. Examine this pattern with a magnifying glass or a microscope, if available. The details of the pattern are beautiful.

Capturing the image

Take a picture with your camera at the highest magnification, zoomed in on the wrinkle pattern as tightly as your camera will allow. Try to hold the camera as steady as possible while doing so. You may have to play around with lighting and background to get an image in which you can see the wrinkle pattern clearly.

In order to be able to convert the distance in the image to a known distance, zoom out and take a picture of a piece of a plastic ruler in the same frame. Focus on the plastic ruler. It's much harder to focus on the drop or sheet (image below).



We suggest taking at least three pictures, with three drops of different size. You can add small drops to the first drop you placed on the film.

All groups will be given two thicknesses of film. Repeat this procedure of cutting, floating and placing a water drop with both films. We'll tell you the thickness of the film.

Image analysis

There are two types of attributes of these patterns we might want to study and understand. The first is the number (N) of the wrinkles, and the second is the length (L) of the wrinkle. Here we focus on the number, N.

Load your images into the ADI programme or any other programme you are used to. Measure the conversion between pixels and millimetres using the ruler. Now use this to measure the radius of the drop (a) in each image.

Next, in every image, count the number of wrinkles you see. This needs patience, and maybe some strategy to mark wrinkles you have counted. If you do not have good enough contrast in your photograph to see the wrinkles all around the drop, then find a section of wrinkles that span, say 90°, count the wrinkles in that section and multiply by four to get N, the number of wrinkles in 360°.

<u>Data collection</u>

Get data for N (# of wrinkles) vs a (drop's radius), for two (or more) different thicknesses t .

Pool data from all groups on a google spreadsheet (*tinyurl.com/wrinkle2019*).

[You can also get data for L (radius of wrinkled zone) vs a (size of drop). We won't do this in class, for lack of time, but will leave analysis of this data for you to try later].

Wrinkling of a floating sheet – Data Analysis

Teachers' programme on Patterns in Nature

We'll work with the data you collected on the number (N) of wrinkles. A similar exercise can be done with the length (L) of wrinkles. The goal is to try and think through how these descriptors of a pattern (dependent variables) are controlled by what you did in the experiment (independent variables).

One idea that we'll use is that in any meaningful equation, units should match on both sides of an equation,

Example: F=ma implies that [Force] = [Mass] x [Length]/[Time]^2

Dependence on drop size (a) and film thickness (t)

We start with the data pooled from all groups on a google spreadsheet (*http://tinyurl.com/wrinkle2019).*

We'll plot N vs a for three thicknesses on a linear plot. Think about the following questions:

I. Does N decrease/increase with a?

II. Is it a linear decrease/increase? Less than linear? More than linear?

III. Next, for a given value of a, does N decrease/increase with t?

IV. Linear? Less than linear? More than linear?

Instead of plotting N against a, let's try to plot some combination of N and t on the y-axis against a on the x-axis.

If you were to use N/t^{α} as new y-variable (where α is some unknown power), based on your answers above, should α be positive or negative? Should it be bigger or smaller than 1?

Try to get "data collapse" of all plots on a single curve, by varying α.

This method is a central tool to find the dependence of a physical observable on a single parameter from a large data set. This allows you to figure out the dependence of N on t.

Now try to find the dependence of N on a. You may try to repeat the previous procedure (i.e. plot Na^{β} and get data collapse by varying β).

[A different and efficient way to do this, is to re-plot the original plots (of N(a)) on log-log scale. In such a log-log plotting, the various plots should appear approximately as parallel linear functions. You can obtain β simply by measuring the slope.]

Dependence on other variables

Now recall our discussion on above on consistency of units. This can tell us quite a bit about the governing physical law. Let's start by recalling that N is a pure number, with no units! Both drop size (a) and thickness (t) have units of length. Unless α and β are the same number, $N = t^{\alpha} / a^{\beta}$ cannot be a valid equation.

This means there must be another physical quantity with units of length that participates in this law. Physically, some possibilities are the elasticity of the sheet , the surface tension of the water, or the gravity of water. Using the table below, suggest possible candidates for a physically-meaningful physical law for N.

Physical constant	**symbol**	**Units**
Elastic (Young) modulus	E	[Energy]/[Length]^3
Surface tension	γ	[Energy]/[Length]^2
Gravitational force	ρ g	[Energy]/[Length]^4

Is there an experiment that can be done to find the correct law?

Much Ado About Wrinkles—Pupil Page

Part A: Objectives

Know:

1. Recognize that spontaneous wrinkling patterns can give you information about materials like skin, plastic and nano-sized films
2. Know that scientists study wrinkling patterns and quantify them to figure out the thickness of materials that are too thin to measure. These materials can be 1-100 nanometers thick. A nanometer is 1 billionth of a meter.

Part B: Wrinkle Detectives—A Simple Controlled Experiment which can be used to model the method of how scientists determine the thickness of nano-scale thin films

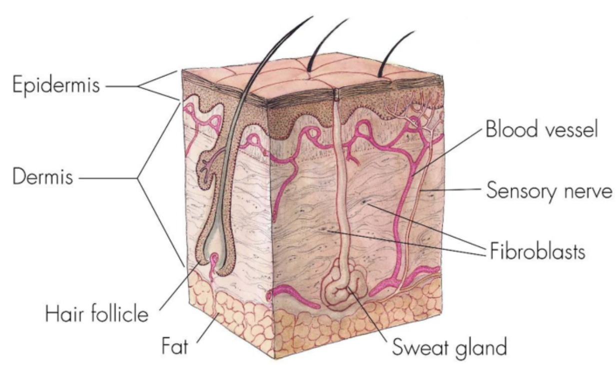
1. Question(s): What can wrinkling patterns tell us about skin?

    Skin is made up of 3 basic layers:

    Epidermis: thin with keratin protein for stiffness

    Dermis: collagen and elastin proteins offer support and elasticity

    Subcutis: fatty layer



2. **Procedure:**
    A. Put your thumb and index finger 3 cm apart on top of the back of your hand. Apply equal forces you're your thumb and index finger to pinch the skin to 2 cm apart. Count the number of wrinkles (peaks). Record your observations in the data table.
    B. Repeat step A on the top of your forearm.

C. Repeat on the underside of your forearm.
D. Repeat the procedure on: upper arm, back of neck, lower leg, etc. Record in the data table.

Testing Area	**Number of Peaks**

E. Extension: test other areas of your body; older people and younger people; males and females; skin exposed to UV and not exposed.
F. Remember: if you want to see if there is difference, only change one variable and keep the other's constant.
G. What kinds of spontaneous wrinkling patterns do you notice?
H. What can you deduce about skin based on your data?

Part C: Wrinkles on a Silicone Sheet Activity—another model which can be used to show how scientists determine the thickness of nano-scale thin films.

1. **Procedure:**
   A. Put a 4 cm x 2 cm strip of corn syrup on a plastic plate. The thickness should be about 4 mm.
   B. Float a 5.5 cm x 1 cm (0.01 inch thick) strip of solid silicone rubber sheet (it is grey) on top of the syrup.

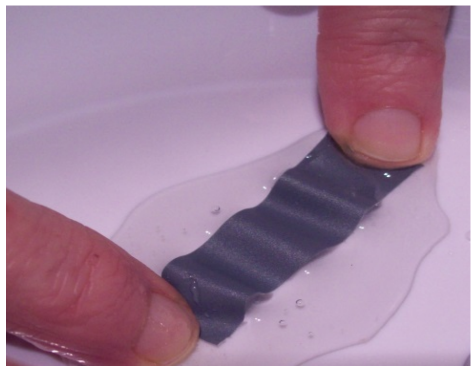
C. Using your index fingers, apply equal force on both sides of the strip toward the center. Observe the wrinkling pattern that spontaneously emerges. Record the number of wrinkles in a data table.

D. Repeat steps a-c using 0.02 inch thick silicone (black).

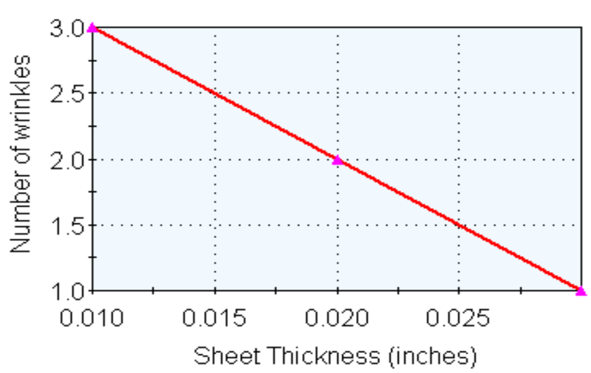
E. Repeat steps a-c using 0.03 inch thick silicone (red)

F. Graph the data. What do you notice?

G. How is this activity related to the wrinkling skin activity? Explain.



Sample Graph

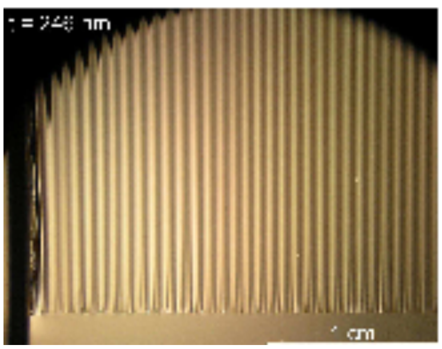


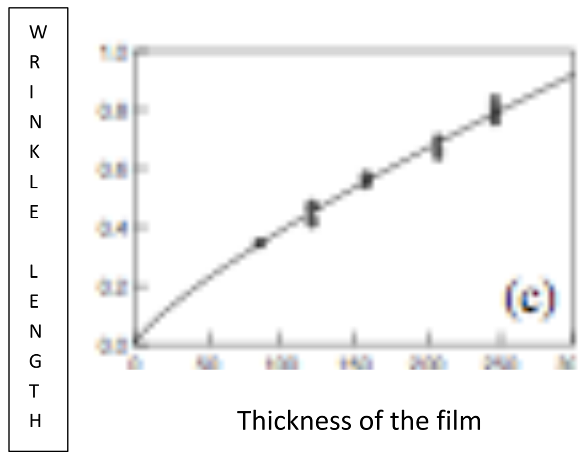
Part D: Real-World Application

Nano-scale materials are made for micro-electronics and memory storage. These materials are very thin—on the scale of 1-100 nanometers. One nanometer is 1,000,000,000 of a meter. 100,0000 nanometers = thickness of a sheet of paper. A comparative scale to help you think of how small a nanometer is: if the Earth's diameter = 1 meter, the diameter of a marble = 1 nanometer.

So, how would scientists measure the thickness of a nano-scale ultra-thin film? Using wrinkles! The thin film is made to float on another substance that it adheres to. Forces are applied to the sides of the film. The spontaneous wrinkling pattern that results can be quantified and used to indirectly measure the film's thickness.

The photograph on the left below is the wrinkling pattern created by applying lateral forces to an ultra-thin film floating on a substance.





Question

1. How can you use the graph to predict the thickness of an ultra-thin film?

Materials: SOLID SILICONE RUBBER SHEETS CAN BE ORDERED FROM: WWW.MARIANCHICAGO.COM
PHONE: 630.293.7800
RED SAMPLE: 0.03 INCHES THICK
BLACK SAMPLE: 0.02 INCHES THICK
GREY SAMPLE: 0.01 INCHES THICK