Online learning activities for
SCIENTIFICALLY THINKING
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Prometheus Books

Nearly every chapter has a box at the end that suggests activities that readers can do to better understand the concepts. You can adapt them to use in your classroom.

But here are some other examples that would not fit into the boxes in the book.

Chapter 1. Science and How to Recognize It

Activity 1. How to make your thinking scientific

Science is the only way of knowing that is based entirely on testing falsifiable hypotheses by examining externally verifiable data. (Class discussion: What does this statement mean?) Everybody thinks scientifically sometimes, and scientists do not always think scientifically.

Below is a list of statements. For each statement,

- Is the statement testable by the scientific method?
- If not, how would you reword the statement so that it could be scientifically testable?

I provide answers to each of these, but the students should generate them. I am sure the instructor can come up with lots of other examples. I would suggest copying the list of questions into a Word document and projecting it to the class for discussion.

1. ***Do proteins contain nitrogen atoms?***
2. ***Which kind of battery lasts the longest?***
3. ***Does high temperature inactivate the amylase enzyme?***
4. ***Which flavor of ice cream tastes the best?***
5. ***Do prison work-release programs decrease the rate of recidivism?***
6. ***Does exercise cause your breath to contain more carbon dioxide?***
7. ***Leaves contain chlorophyll.***
8. ***God answers prayers.***

Here are some suggested answers to the questions:

1. *Do proteins contain nitrogen atoms?* This statement can be tested scientifically, though not easily in a school lab.

2. *Which kind of battery lasts the longest?* This statement can be tested scientifically. You might discuss with your students the variables that would need to be standardized, such as voltage, amperage, etc. Also, are you comparing different kinds of batteries, or different brands of the same kind?

3. *Does high temperature inactivate the amylase enzyme?* This statement can be tested scientifically. The reaction is relatively easy to perform in test tubes, in which starch > glucose in the presence of amylase. The control would be a test tube with no starch; the treatments would be a test tube at body temperature, and another test tube in a hot water bath. Glucose concentration can be measured by allowing it to react with Benedict's solution in boiling water, *after* the reaction has finished. High temperatures inactivate the enzyme. You can add a further investigation: after keeping the enzyme and sugar in a hot water bath, let it cool down and then see if it works. This demonstrates that the inactivation (denaturation) is permanent.

4. *Which flavor of ice cream tastes the best?* This statement cannot be tested scientifically. But it can be reworded to something like: Which flavor of ice cream sells the best? In this case, several factors would need to be controlled, such as:

- Nation and ethnicity
- Economic bracket
- Portion size
- Time of year

and many other variables. See how many your students can think of.

5. *Do prison work-release programs decrease the rate of recidivism?* (A good word for students to learn.) This statement can be tested scientifically. In this case, the subject matter is not what is usually called "science." "Social studies" topics can be investigated scientifically, using data available online.

6. *Does exercise cause your breath to contain more carbon dioxide?* This can be tested scientifically. If you begin with two equal amounts of dilute sodium hydroxide, a base, and add phenolphthalien, the water turns purple. Blowing bubbles through a straw introduces carbon dioxide from the breath into the solution, where it becomes carbonic acid and neutralizes the base and, eventually, the purple color will vanish. If your (pre-exercise) breath has less carbon dioxide in it, you have to blow the bubbles longer than with your (post-exercise) breath, which contains more. The dependent variable, therefore, is the length of time you have to blow bubbles. Students love this activity, because they have to exercise for two minutes, and they can find some pretty creative ways of doing this.

7. *Leaves contain chlorophyll.* Leaves are green, but how do you know the green color is chlorophyll, and not something else that is also green? Students can extract chlorophyll (done most safely by grinding a leaf in alcohol), generating an absorption spectrum with a spectrophotometer, if your school is lucky enough to have one, and

then comparing the spectrum with that of chlorophyll, available online. You can also note that chlorophyll does not dissolve in water, the way some other green pigments do. For further discussion: some leaves do not, in fact, contain chlorophyll.

8. *God answers prayers*. This statement cannot be tested scientifically. But it can be reworded to something like: *Do prayers cause something different to happen than would have happened without them?* This statement tests the efficacy of human prayer, without speculating on whether there is a God or not. A detailed example of this is presented in Chapter 13. This is also an excellent chance to discuss:

- Investigator bias (in which people notice when prayers seem to be answered and ignore, or explain away, those times when prayers seem to fail) and
- The placebo effect, in which recipients of prayer feel better just because they know they are being prayed for. How would you design an experiment that would eliminate the placebo effect? Again, the example in Chapter 13 serves as a good example.

Chapter 3: Experimenting with a Mountain

Activity 2. The Donner Party

Sometimes hypotheses can be tested using data sets that were recorded for some completely different purpose. One example of this is the story of the Donner Party.

The Donner Party was a group of settlers, led by George Donner and James F. Reed, who organized a wagon train in 1846 to move to California. The journey usually took four to six months, but the Donner Party traveled a different route, which took longer. They did not reach the Sierra Nevada mountains of California until November. They got caught in heavy snowfall near a mountain pass and lake now named after them. For four months, the remaining Donner Party members had to survive a very cold winter. They had anticipated arrival in California before winter, therefore they had almost no food remaining by the time they were trapped. Their oxen froze, but even this source of meat was soon depleted, and they boiled ox-hide into gruel. They had built cabins, but the roofs were of ox-hide. Some of them ate their roofs. As tensions rose, some party members insisted on the immediate repayment of debts; one family took another family's roof, and ate it. One man went crazy, stripped off his clothes, ran into the woods, then came back and died.

This story is most infamous because, legend has it, the starving people began to eat one another. It is unlikely that anybody actually killed another person in order to eat them. But, if fresh meat was just lying there, what starving person could resist it? And, according to one of several conflicting reports, two men were murdered to be eaten, but only after they were almost dead.

Modern accounts of the Donner Party story can be found in Daniel James Brown's *The Indifferent Stars Above* (William Morrow, 2015); Ethan Rarick's *Desperate Passage: The Donner Party's Perilous Journey West* (Oxford University Press, 2009); and Michal Wallis's *The Best Land Under Heaven: The Donner Party in the Age of Manifest Destiny* (Norton, 2017).

The main story of the Donner Party was that some people survived the cold and starvation better than others. Among the factors that could influence how long a person can survive out in the cold are these:

- *Gender: physiology.* Men have a higher metabolic rate than women. Women also store more fat in their bodies than men. (Women store subcutaneous fat under their skin, which is why their skin is so smooth.) Hypothesis: Women survived longer than men in the Donner Party.
- *Gender: behavior.* Men tend to be more active in these situations. If somebody has to go look for a dead horse to eat, or fight with someone, it is more likely to be the man. Hypothesis: Women survived longer than men in the Donner Party.
- *Age.* Very young and very old people might be more likely to starve and freeze. On the other hand, people might shelter their children from the cold and give them more food than they might even keep for themselves. Hypothesis: survival rate was different in each age category.
- *Family membership.* Does being a member of a family give you a survival advantage over being a single individual? Hypothesis: People in large families survived longer than single individuals.

Although the actual data of who survived and who did not cannot definitively indicate a role of metabolism, or fat, or behavior in any of the above questions. But the hypotheses can be tested and this might help fill in a little bit of the history of this event.

The following table presents the names, gender, and age of each member of the Donner Party and whether they lived or died. I have omitted people who were known to have been shot or otherwise murdered, and those whose age, gender, or last name were not recorded. Based on this table, the students should be able to calculate:

- The percentage of men who survived.
- The percentage of women who survived.
- The percentage survival of men, and of women, who survived in each of these age categories: 10 years old or younger; 11 through 25 years; 26 through 40 years; and over 40.
- The percentage survival of people in each of the large families (indicated by shared last name). (Watch out for them Breens and Reeds!)
- The percentage survival of single individuals (indicated by a unique last name).

Notice that having the same last name does not indicate genetic relatedness; it could represent relationship by marriage. Thus, without further information, you cannot use these data to test for genetic effects on the ability to survive cold and starvation.

Name	**Gender**	**Age**	**Survived?**
Edward Breen	M	13	Y
Isabella Breen	F	1	Y
James Breen	M	4	Y
John Breen	M	14	Y
Mary Breen	F	40	Y
Patrick Breen	M	40	Y
Patrick Breen, Jr.	M	11	Y
Peter Breen	M	7	Y

Simon Breen	M	9	Y
Charles Burger	M	30	N
John Denton	M	28	N
Patrick Dolan	M	35	N
Eliza Donner	F	3	Y
Elizabeth Donner	F	45	N
Elitha Donner	F	11	Y
Frances Donner	F	6	Y
George Donner	M	62	N
George Donner, Jr.	M	9	Y
Georgia Donner	F	4	Y
Isaac Donner	M	5	N
Jacob Donner	M	65	N
Leanna Donner	F	12	Y
Lewis Donner	M	3	N
Mary Donner	F	7	Y
Samuel Donner	M	4	N
Tamsen Donner	F	45	N
Eleanor Eddy	F	25	N
James Eddy	M	3	N
Margaret Eddy	F	1	N
William Eddy	M	28	Y
Milton Elliot	M	25	N
Jay Fosdick	M	23	N
Sarah Fosdick	F	22	Y
Sara Foster	F	23	Y
George Foster	M	4	N
William Foster	M	28	Y
Eleanor Graves	F	15	Y
Elizabeth Graves	F	47	N
Elizabeth Graves, Jr.	F	1	N
Franklin Graves	M	57	N
Franklin Graves, Jr.	M	5	N
Jonathan Graves	M	7	Y
Lavina Graves	F	13	Y
Mary Graves	F	20	Y
William Graves	M	18	Y
Luke Halloran	M	25	N
?? Hardkoop	M	40	Y
William Herron	M	25	Y
Solomon Hook	M	14	Y
William Hook	M	12	N
Noah James	M	60	N
Ada Keseberg	F	3	N
Lewis Keseberg	M	32	Y
Lewis Keseberg, Jr.	M	1	N

Philipine Keseberg	F	32	Y
Amanda McCutcheon	F	24	Y
Harriet McCutcheon	F	1	N
William McCutcheon	M	30	Y
John Murphy	M	15	N
Lavina Murphy	F	50	N
Lemuel Murphy	M	12	N
Simon Murphy	M	10	Y
William Murphy	M	11	Y
Mary Murphy	F	13	Y
Catherine Pike	F	3	N
Harriet Pike	F	21	Y
Naomi Pike	F	3	Y
James Reed	M	46	Y
James Reed, Jr.	M	5	Y
Margaret Reed	F	32	Y
Patty Reed	F	8	Y
Thomas Reed	M	3	Y
Virginia Reed	F	12	Y
Joseph Reinhardt	M	30	N
Samuel Shoemaker	M	25	N
James Smith	M	25	N
Augustus Spitzer	M	28	N
Charles Stanton	M	30	N
Jean Trubode	M	23	Y
Baylis Williams	M	24	N
Eliza Williams	F	25	Y

Chapter 4. Wright and Rong

Activity 2. False positives and false negatives. The book suggests generating a scientific hypothesis and specifying a false positive and a false negative for each. Here are some specific examples. I am sure you can think of others! And do not actually do any of these tests.

1. Vitamin C prevents colds.
2. Vitamin C cures colds.
3. Inadequate sleep slows down your reaction times for making quick decisions.
4. Gasoline with 10 percent ethanol has better fuel efficiency than gasoline without ethanol.
5. The body of a person with blood type O will reject a transfusion of blood type A.
6. Some people are more allergic to poison ivy than others.

Each student group receives one statement. For that statement, the group writes:

- The false positive
- The inconvenient, expensive, or dangerous consequences of believing the false positive
- The false negative
- The inconvenient, expensive, or dangerous consequences of believing the false negative

Chapter 5: A World of Illusion

Activity 3. Color is an illusion

As explained in the book, color is an illusion. Discrete bands of color, such as in a rainbow, do not really exist in nature. All that exists is photons with a continuous range of wavelengths, from about 400 nm (nanometers) in the blue to about 700 nm in the red part of the spectrum.

The reasons that humans (and other animals) see discrete colors are:

- We have light-sensing cells in our retina (“cones”) that react to a range of wavelengths of light. Each kind, even though their ranges of sensitivity overlap, has its own peak sensitivity. In humans, the three kinds of cones have peak responses to red, green, and blue light.
- These cones send nerve impulses to the visual cortex of the brain along the optic nerves.
- The visual cortex uses this information to construct an illusion of color.

This is the reason that a color cathode ray tube or monitor uses triplets of red, green, and blue dots in its pixels (“picture elements”). If you have access to an old cathode ray tube, whether for an old television or computer, you can see these triplets with a magnifying glass and show them to your students. You can also see it in color photos from old newspapers and magazines. Newer monitors, and cell phone screens, use the same principle but the pixels are too small to see with a magnifying glass. The red, green, and blue (“RGB”) elements of each pixel correspond closely to the peak sensitivity of our cones. Each RGB component has its own relative intensity; for example, pure red in a printed photo consists almost completely of red dots.

This is how we see color in the natural world:

Wavelengths of light > differential stimulation of cones > impulses to the brain

This is how we see a color picture:

RGB dots > differential stimulation of cones > impulses to the brain

With the exercise here described, you can demonstrate to your students that color is an illusion by doing the following:

- A student decides which color corresponds to each wavelength of light, in 10 nm increments.
- A student notes the RGB components for each of these wavelengths.

Methods

1. Find an image online of a light spectrum. For copyright reasons, I cannot supply one here, but they are easy to find. You could try to use an image of a rainbow, but they are typically unclear and thus more difficult to work with. This image should have the wavelengths of light, usually in 10 to 50 nm increments, indicated along the bottom (the horizontal axis). Make this image available to your students.
2. The student opens the image in a program such as Microsoft Paint, which is bundled with the suite of office programs. The following instructions are specific for Paint.
   a. The student clicks on the little dropper tube. A circle appears.
   b. Move the cursor (which moves the circle) to a spot immediately above the first wavelength, e.g., 400 nm, within the spectrum itself.
   c. Click on the color in the box right beside the dropper. The screen that now appears will give the RGB components.
3. For each *approximately* 10 nm of wavelength, the student should note in a table such as the following:
   a. A subjective indication of the color as he or she sees it, such as yellow, orange, or red.
   b. The R, G, and B components as indicated by the image program.
   c. Click “OK” to go back to the image.
   d. Start with 400 and continue until you reach 700 nm.

Here are the results that I obtained from doing this project. Each student will get slightly different results, depending on exactly where they happen to place the circle.

Wavelength	Subjective color	Red	Green	Blue
400	purple	100	1	120
410	purple	88	0	188
420	bluish purple	67	0	168
430	blue	30	1	217
440	blue	3	1	248
450	blue	11	42	254
460	blue	29	95	254
470	light blue	36	125	255
480	light blue	45	153	254
490	greenish blue	59	220	258
500	bluish green	37	253	137
510	green	16	245	67
520	green	7	251	29

530	green	1	254	5
540	green	52	251	10
550	yellowish green	87	248	14
560	yellowish green	124	246	21
570	greenish yellow	147	242	26
580	greenish yellow	205	236	34
590	yellow	250	217	40
600	yellow	247	176	32
610	orangish yellow	244	132	24
620	orange	242	88	16
630	reddish orange	241	77	14
640	orangish red	237	25	4
650	red	230	0	0
660	red	224	0	1
670	red	216	0	1
680	red	204	0	3
690	red	194	0	0
700	deep red	183	0	2

Results and discussion

Each student will get a slightly different answer for each subjective color. For example, I have never been able to discriminate indigo (of the famous VIBGYOR spectrum). If students or student groups disagree, this is a teachable moment. Among the conclusions everyone will notice are:

- Some colors are represented by a considerable range of wavelengths: blue from 430 to 460, green from 510 to 540, yellow from 580 to 610, red from 650 to 700.
- From the viewpoint of the RGB components, and in the retina, there is no such thing as yellow. Yellow is mostly a combination of red and green to your brain.
- If you click the dropper on white space, you will find that all colors are more or less equally represented (I got 255, 255, and 255).
- Mixing different colors of paint does not present this result.

This activity presents an excellent opportunity for color graphing, by computer or on paper. The wavelength is the independent variable; this is where you also indicate the subjective color. The dependent variable is the RGB value (blue line for blue, green line for green, red line for red).

Discuss the possible evolutionary reasons why our brain should present us with a view of the world that has discrete colors, rather than subtly shifting wavelengths. Some possible ideas are in *Scientifically Thinking.* You can also use the author’s Darwin Channel video at: http://youtu.be/YxpUtdWxkAk.

Wavelength (nm)	Subjective color	RGB components		
		R	G	B
400				
410				
420				
430				
440				
450				
460				
470				
480				
490				
500				
510				
520				
530				
540				
550				
560				
570				
580				
590				
600				
610				
620				
630				
640				
650				
660				
670				
680				
690				
700				

Chapter 6: Just Measure It!?

Activity 4. Sensory fatigue

Whenever you feel an object, your nerve endings send signals through sensory neurons to your brain. As long as you continue to touch, or be touched by, the object, these nerve signals continue. However, if the signal remains unchanged for a long enough period, your brain will begin to ignore the signals. This activity is a simple demonstration of this "sensory fatigue."

1. Obtain a coin and place it on your horizontal arm. You can feel this coin when it is first placed.
2. Measure the length of time, in minutes, that it takes for you to no longer be able to feel the coin.

Discussion

Discuss the possible evolutionary reasons why your brain begins to ignore unchanging information. How could ignoring information possibly be a survival advantage? Also, the changing sensitivity of touch is one reason your nerves are not a valid way of measuring pressure or weight.

Activity 5. Sensory acuity: Two-point discrimination

When your skin is being pricked by a sharp point, you can feel it. When your skin is pricked by two sharp points, you can feel two points, unless they are very close together, then they feel like a single point. Your ability to feel them as separate points depends on the number of nerve endings per unit area on your skin, that is, the density of pain sensors.

Methods

1. You will need a lab partner for this activity.
2. Obtain a compass with two sharp points (see figure).

3. Push the two points at least a couple of centimeters apart.
4. The subject should keep his or her eyes closed during this activity.
5. The tester should press the two points against the subject's skin. Do not poke the points into the skin! You should be able to feel two points.
6. Push the two compass points a little closer together and try it again. Subject: Do you still feel two points?
7. Keep repeating steps 5 and 6 until the points are close enough together that you can no longer distinguish them. This is the *two-point discrimination distance.* Measure the distance between the two points on the compass in mm with a ruler.
8. Do this procedure for different parts of your body. Because it is difficult for you to reach some of these places, you should work with a lab partner (one you trust to not gouge you with the compass!). These are some examples of different places on which you can make these measurements. You will have one number (in mm) for each of these:

Location on body	Two-point discrimination distance (mm)
Fingertip	
Back of hand	
Palm of hand	
Inside of elbow	
Front of neck	
Back of neck	

Discussion

Interpret the results in terms of evolutionary survival value. Which parts of the body would benefit from having the greatest density of nerve endings, and why? Also, the differing sensory acuity of different parts of your skin is one reason why your senses are not a valid way to measure how far apart two points are.

Activity 6. Sensory acuity: Recognition of location

If you feel something on your skin, how good are you at locating the stimulus? You would expect that it is easier to locate a stimulus on a part of the skin that has the greatest density of nerve endings.

Methods

1. You will need a lab partner for this activity.
2. The subject and tester should each have a differently colored marker. These should be non-toxic, non-permanent markers!
3. The subject should keep his/her eyes closed during this activity.
4. The tester touches the subject's skin with the his/her marker.
5. The subject then tries to touch the same place with his/her marker.
6. Do this activity for each of the locations indicated in the table.
7. The distance between the two dots at each location is the "error distance."

Location on body	Error distance (mm)
Fingertip	
Back of hand	
Palm of hand	
Inside of elbow	
Front of neck	
Back of neck	

Discussion

Which part of the body had the most, and which had the least, accuracy in determining the location of the touch stimulus? Come up with an evolutionary explanation as to why some parts of your body has greater accuracy (less error distance) than others. Also, the differing sensory acuity of different parts of your skin is one reason why your senses are not a valid way to determine where a stimulus is located.

Chapter 19. The Scientist in a Political World

Activity 7 (three parts).

One of the examples of the way science has an unavoidable impact on political issues is *global warming*. Here follow a series of three investigative activities in which students can:

- Estimate the *size* of a tree, how many branches it has, and how much leaf area it has. This will always prove surprising to them, for example that a large oak tree might have between 50,000 and 90,000 twigs. This activity gives the students practice with very simple trigonometry.

- Estimate the *air conditioning capacity* of the tree that they measured. Given the leaf area and an average transpiration rate, how much heat is consumed by the evaporation of the water? This represents the “air conditioning power” of a tree for its immediate environment. Of course, the heat does not vanish; it goes up into the air, away from the leaves and away from whoever happens to be in the shade. The students can then convert the total number of kilocalories of transpiration for their tree during a typical summer month, and convert that into kilowatt-hours and the amount of money on an electric bill. Well-placed trees can cut back on your electric bill, and on the release of carbon dioxide from power plants, though not as much as these calculations suggest.

- Estimate the *amount of carbon dioxide that the tree can absorb*. Given the leaf area and an average photosynthetic rate, how many metric tons of carbon dioxide does the tree absorb during a typical growing season? The students also use online resources to calculate their “carbon footprint” for this same period of time. Then, by dividing the two numbers, they can calculate how many trees it would take to offset their carbon footprint.

The result is nearly always surprising and might make them take serious steps to reduce their direct and indirect carbon emissions. Note that this project only works in the forested zones of North America.

Here are the three handouts that the author has used in his classes.

INVESTIGATIVE PROJECT
ECOSYSTEM SERVICES OF TREES, Part One.

In this project, you will (working in groups) figure out how much of an impact on the ecosystem results from the activities of trees: the cooling effect of transpiration of water vapor, and the amount of carbon dioxide that the tree absorbs. This information is very important for making decisions about preserving or planting trees on residential and commercial land. Some builders begin by clearing all trees away ("improving the land"). But it might be more cost-effective for the occupants of the building if the trees are allowed to remain. That is, *the trees provide a direct economic benefit to the world economy, and often to the economy of the individual land owner.* But how much? That is what we want to calculate.

This sounds like an easy project, until you start thinking about all of the variables involved. And guess what—you get to figure out what to do about these variables. The answer that you get at the end, however, should be useful and interesting.

Today we will estimate the number of twigs on a typical tree. Before the leaves open on your tree, your group will need to estimate the size of the tree.

I. Estimating the outer canopy area of your tree. Tree canopies have complex shapes, but we can estimate the outer canopy area by making the simplifying assumption that the canopy is a hemisphere.

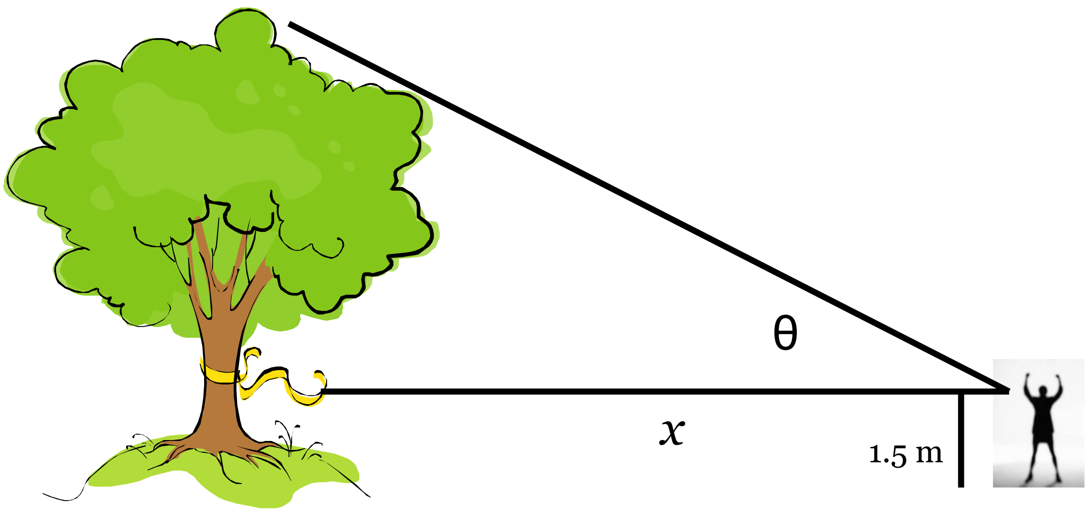
First, you will need to know the *canopy radius*. The radius of the canopy is the difference between the height of the tree and the height above the ground at which the canopy begins. For example, if the tree is 15 meters tall and the canopy begins at 5 meters above the ground, then the canopy radius is 10 meters.

Once you estimate this canopy radius, the surface area of a sphere is $4\pi r^2$ which means that the hemisphere area is $\mathbf{2\pi r^2}$.

A. Estimating the height of the top and bottom of the canopy by triangulation (see figure).

1. Someone in your group should hold the end of a measuring tape at the base of the tree, and someone else should extend the tape and walk away from the tree far enough to have a clear view of the top. Note down this "distance from the trunk", which is the x axis of the right triangle.

2. Then, using a clinometer, the person at the end of the measuring tape should measure the angle that you must tilt to see the top of the tree, in degrees. This is the angle theta (θ). Record this angle.



3. Calculate the height of the tree. This is the height of the tree *above eye level (y)*. Since tan θ is y divided by x, it follows that

$$y = x \tan \theta$$

To this height y, add your height in meters (approximately 1.5 meters). This is the height of the tree, which you should record.

Tree number	___________
Distance (x)	___________
Angle (θ)	___________
Tan θ	___________
Height of top of tree	___________

B. Estimating the height of the bottom of the canopy. If the bottom of the canopy is within reach, you may be able to measure it directly with the meter tape. If not, use the same procedure described above to calculate the height of the bottom of the canopy.

Tree number	__________
Distance (x)	__________
Angle (θ)	__________
Tan θ	__________
Height above ground	__________

Subtract the top of the canopy from the bottom of the canopy to get the *radius.*

Radius ________ m

From this, using the formula, calculate the canopy area.

Canopy area _________ m^2

Note: all work must be done in metric units.

II. Estimating the number of smallest branches of the tree

Now you need to know the number of smallest twigs per square meter of canopy surface. How would you do this? You will have a square meter frame and, if necessary, a stepladder. A twig is the smallest woody branch that will have leaves on it later in the spring. Once you know the number of twigs in a typical square meter, you can multiply this number by the number of square meters on the canopy surface.

It is possible that some parts of your tree's canopy do not have branches and twigs. If this is the case, visually estimate the proportion of missing twigs. For example, if it looks like your canopy has twigs over only about ¾ of its surface, then multiply your estimate by 0.75. This procedure will give you your *revised* estimate.

Tree	______________
Number of twigs per m^2	______________
Canopy area (m^2)	______________
Estimate of total twig number	______________
Revised estimate of total twig number	______________

Names of people in your group: ____

INVESTIGATIVE PROJECT
ECOSYSTEM SERVICES OF TREES, part two.

The process of transpiration cools the leaves of the trees, but also just happens to cool the human beings who are under the trees. The evaporation of one gram of water uses about 600 calories of energy (0.6 kilocalories or "Calories" as the term is commonly used). By doing this project, you will be able to calculate a rough equivalence between a tree and air conditioning units. This will allow you to estimate the number of kilowatt-hours of electricity that a tree might be able to save for its immediate environment, which may include a building in its shade.

For one thing, no two trees have identical transpiration rates. Your group will focus on just one tree. Among the ways that tree species differ are:

- *Tree species.* Some tree species transpire more water than others, even relative to the amount of leaf area that they have. Some species, such as the post oak, have thicker leaves and may have a lower transpiration rate than other species, such as the black oak.
- *Environment around the tree.* Trees that are out in the open may transpire more than trees that are surrounded by other trees, because (1) they receive sunlight from the sides, especially the south, rather than just from the top, and (2) the wind blows around them more than around trees in a dense forest.

Earlier, you estimated the number of twigs on your tree. Use this estimate for the calculations below:

1. Based on previous years' transpiration measurements, *each twig* transpired about *3 grams of water per hour.* That is, multiply your tree's twigs by 3. Calculate the number of grams of water per hour that your tree transpires. _____________ g/hr

2. Now convert your grams of water to kilocalories. Remember that the evaporation of a gram of water uses about 0.6 kilocalories of heat, which comes from the air. That is, the latent heat of evaporation is about -0.6 kilocalories (a negative number). _____________ kcal/hr

3. Assume that a day is 10 hours long and a month is 30 days. How many kilocalories per month does your tree account for? _________ kcal/mo

4. Use a conversion factor to figure how many kilowatt hours of electricity it would take to have an air conditioner do this work. One kilowatt hour takes about 860 kilocalories of evaporation. Transpiration in your tree accounts for ____________ kwh/month.

5. How much would this many kwh cost? On one of my recent electric bills, each kilowatt hour costs 22¢. $__________ per month.

Now interpret your results by writing a short paper (about 3 pages, not counting cover page [if you use one] and references). The paper should include:

1. Introduction: The benefit that plants derive from transpiration
2. Methods: A brief summary (not all the details) of what we did and how you did your calculations. This would include a brief discussion of how we estimated the number of twigs on your tree.
3. Results: What were the numbers that you calculated? Include units.
4. Discussion:

The number you calculated tells how much cooling *of the air in general* that your tree is responsible for. If you had a house in the shade of this tree, you would not actually save this much money, unless your house was a treehouse up in the canopy. But your tree would contribute to a cooler environment. But think about how much electricity savings you might be able to have. Consider the following points as you write this interpretation:

- Some tree species transpire more than others. But the rapidly-growing trees, such as hackberries and cottonwoods, also have the unfortunate habit of dropping big limbs or even falling over when they get big. Identify some tree species that would offer good shade without being as dangerous to your house. Generally speaking, the safest trees to have around your house would be oaks. Different species of oaks grow in different kinds of forests: for example, white oaks in the northeast, water oaks in the southeast, bur oaks in the northwest part of the North American forest zone, and post oaks in the southwest part of the forest zone. In the Pacific Northwest, dougfirs or bigleaf maples might serve.

- Where should the tree be, relative to your house? Consider that insurance policies often prohibit tree branches directly over a building. In your interpretation, indicate what you would suggest to a builder regarding the arrangement of trees and buildings, to make the best use of the air conditioning provided by the trees. Remember also that the trees cool the air in the vicinity of the building, even if the building is not directly under or beside them. Based on all of this, make a reasonable estimate of how much energy savings you might have.

- Also include a discussion of “green roofs.” “Green roofs” are becoming increasingly popular. Plants on the roof itself will cool a building by transpiration. “Extensive green roofs” have small plants, with a little bit of transpiration; “intensive green roofs” have large shrubs and small trees, with a lot of transpiration. What are the costs and benefits of each? You can find numerous sources for this information. One such source is the author’s book: Rice, Stanley A. *Green Planet: How Plants Keep the Earth Alive.* Rutgers University Press, 2012.

5. References. You should cite at least two sources for this. Sources may include popular scientific magazines, newspapers, and websites of official organizations (for example, epa.gov) and specialized companies (e.g. suppliers of green roofs). You will probably want to avoid actual scientific journals. *Sources such as Wikipedia, about.com, textbooks, and dictionaries are not acceptable references;* they may be good places to start but are not good places to end. Blogs and websites with strong political agendas *(even mine)* are generally not good sources: many bloggers probably don’t know any more about a

subject than you do. And please do not cite *Green Planet* as a source; you may use the references therein, if you can find them yourself. Each reference should be cited in the paper itself. List references at the end alphabetically. These are the formats generally used by publishers:

For popular magazines:
Heinrich, Bernd, and Thoma Bugnyar. "Just how smart are ravens?" *Scientific American*, April 2007, 64-71.
For books:
Friend, Tim. *Animal Talk: Breaking the Codes of Animal Language*. New York: Free Press, 2004.
For websites:
National Institutes of Health. "National Center for Biotechnology Information." Available online. URL: http://www.ncbi.nih.gov. Accessed July 12, 2008.

INVESTIGATIVE PROJECT
ECOSYSTEM SERVICES OF TREES, part three.

1. There are numerous websites that you can use to calculate your carbon footprint, including

    - Climate Care, which also calculates the numerical costs of your carbon footprint (in British pounds): https://climatecare.org/calculator/
    - Carbon Fund, which also calculates the carbon cost: https://carbonfund.org/individuals/.

2. However, we will use The Nature Conservancy carbon footprint calculator (http://www.nature.org/greenliving/carboncalculator/index.htm) to calculate the number of tons of CO_2 equivalent that you produce. **Before starting, you will need to know:**

- **How many people live in your household**
- **Your approximate household income**
- **How many miles you drive in a year**
- **What the fuel efficiency is for your vehicles**
- **Air or public transit travel**
- **Your annual electric bill (dollars)**
- **Your annual gas bill (dollars)**
- **Heating oil bill (if any)**
- **Square feet of living space in your home**
- **Your annual water bill (dollars)**
- **Approximately how many calories you consume per day in the major food groups**
- **How much you spend per month on goods**
- **How much you spend per month on services**

Please **bring this information with you to the lab meeting.**

3. By entering this information in the Nature Conservancy calculator, you can find out how your carbon footprint compares to that of the average American. Note that to enter this information, you may have to click on the blue dot and move it around.

4. Indicate

   Your carbon footprint ___________________.
   How your carbon footprint compares to that of the average American _________.

5. Based on the numbers you provided at each step (you can always go back and check them), identify some areas in which you can *realistically* reduce your carbon footprint. Indicate one or more ways that you can do this in the space below. Note, do not make outlandish claims, such as "I will buy a hybrid car" if you cannot afford to buy a car. Make it real for your situation. Maybe you cannot afford new insulation for your house, but you might be able to keep the thermostat a little lower in the winter and higher in the summer, thus reducing both your utility bills and your carbon footprint.

   Ways I can reduce my carbon footprint:

6. Then *make a new estimate* of your carbon production by changing the things you have identified. That is, enter revised numbers into the calculator. Your new estimates. Indicate:

   Your *revised* carbon footprint ___________________.
   How your *revised* carbon footprint compares to that of the average American _________.

7. Then sign a contract with yourself:

   I will make a sincere effort to institute the changes I indicated above:

   Signed_________________________________ Date ______________________

8. Now we will calculate an answer to this question: *How many trees would it take to absorb the amount of carbon dioxide you produce?* Follow these instructions to make your calculations.

   Number of twigs on your tree. This number comes from the tree measurement lab that you did earlier in the semester.

   ____

Assume your twig has 100 cm^2 of leaf area. How many cm^2 of leaf area does your tree have?

____

How many m^2 of leaf area does your tree have? Note that these are in square units.

____

Assume that a typical photosynthetic rate is 10 g m^{-2} day^{-1}. How many **grams** of CO_2 could your tree absorb from the air on a typical summer day?

____

How many **kilograms** of CO_2 could your tree absorb from the air on a typical summer day?

____

Assume that the tree can keep this photosynthesis going for about 200 days (that is, not counting late fall, winter, and early spring). How many **kg** of CO_2 could your tree absorb from the air in a typical year?

____

How many **kg** of carbon dioxide do you produce in a year? 1 ton = 908 kg.

____

How many trees would it take to compensate for your carbon emissions?

____

The author has also provided Darwin Channel videos to facilitate discussion:

Chapter 1. How to break down a complex system, such as a forest with plants, herbivores, predators, and decomposers, into a simple experiment, based on a study that was published in Science magazine (Hawlena, Dror, et al. "Fear of predation slows plant litter decomposition," *Science* 336 (2012): 1,434-1,438). https://youtu.be/ddg8EqoZIEg

Chapter 1. The author described how he and his student investigated the role of smoke in causing seed germination in a wildflower species. See also this video: http://youtu.be/1bnJa7yYkyM.

Chapter 1. In science, you have to think for yourself rather than just believing what you are told, even if it is something Charles Darwin tells you!
http://www.youtube.com/watch?v=Ty14hTipFG8

Chapter 2. One of the most famous science fiction writers, widely considered the father of science fiction, was Jules Verne. Even though he was very good at testing hypotheses with evidence, his extrapolation into the future was way, way off. Many products of human and evolutionary history are almost unpredictable: https://youtu.be/QSvsj_YBPaI.

Chapter 2. In this video, Charles Darwin explains why he loves to watch Perry Mason reruns: they, like many other mystery stories throughout history, use the scientific method: https://youtu.be/SdU0jD27m4Q.

Chapter 5. We cannot trust our senses for scientific measurement. Our senses create a world of illusion (which can be beneficial) and delusion (which can be dangerous): http://youtu.be/YxpUtdWxkAk.

Chapter 10. Charles Darwin explains how what we interpret as intelligence and empathy may be just an illusion. How would you ever know if your cat is empathetic? This video is based on a Science paper (Langford, Dale J., et al. "Social modulation of pain as evidence for empathy in mice." *Science* 312 (2006): 1,967-1,970). See http://youtu.be/3vFdcKJumJU.

Chapter 13. One example of a pervasive bias is that most of us think that Neanderthals were rather stupid. But recent discoveries suggest that this was not the case, as explained in this video, "Darwin apologizes to Neanderthals," https://youtu.be/nDM-zLUqj-s.

Chapter 17. Natural selection is the biggest idea ever, and it is makes a life-or-death difference in our health. Bacterial populations evolve resistance to antibiotics, as explained in this Darwin Channel video: https://youtu.be/BVLabvOs8ik.

Chapter 17. In this video, Charles Darwin uses cats as an example of natural selection. See http://youtu.be/S_zrEmH8jmg.

Chapter 20. Darwin visits the George Washington Carver National Monument in Missouri, and contemplates the life and work of this great and humble scientist: http://youtu.be/okynvvXcOGQ.

Chapter 22. Science is an adventure! Darwin almost falls off a cliff as he tells you about scientific adventures: http://youtu.be/bnFQPrBg3II.