

Transpiring Trees

Plant Transpiration and the Water Cycle

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Grade Level	9th – 12th Grade	**Time Frame**	5-10 class period(s)
Subject	Science	**Duration**	275 minutes
Course	Biology		

Essential Question

Overarching Essential Question: How does matter cycle through ecosystems? Topical Essential Question: What part do trees play in natural cycles?

Summary

Students will investigate the water cycle and how water flows through ecosystems. Students will use statistical analysis and mathematical reasoning to develop models that can determine the factors that contribute to a tree's influence on matter and energy cycles within an ecosystem. Students will apply this knowledge to real life data sets to make predictions about how drought conditions may affect trees and the cycles they influence. Acknowledgement: This material is based on work supported by the National Science Foundation under Grant No. IIA-1301789. Any opinions, findings, and conclusions expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation or Oklahoma State Regents for Higher Education.

Snapshot

Engage

The students view a short video about forestry in Oklahoma and discuss the question, "Why are trees important?" During this discussion the students create a list of reasons they think that trees are important and share these reasons with the class.

Explore

Students create a mathematical model to measure and calculate leaf surface area. Students investigate tree transpiration by measuring the water use of a single tree limb over time and comparing this to stem size, limb length, and total leaf surface area. Students apply this mathematical model in an investigation to determine what factors most closely correlate with tree transpiration rates.

Explain

Students analyze their data using statistical analysis. Through this analysis students discover that total leaf surface area has the most impact on tree transpiration rates. Students observe tree anatomy to construct explanations for why leaf surface area had the greatest effect on transpiration. Students also create a model of the water cycle to identify how trees fit into that cycle.

Extend

Students read a journal article from the PINE MAP study (a study researching drought's effect on Loblolly Pines) and identify similarities and differences between the research methods and results from the study and the students' investigation.

Evaluate

Students are given real data from the PINE MAP research study and use their findings and models to analyze and make predictions regarding the Loblolly Pine and its response to drought as well as its role in the ecosystem.

Standards

ACT College and Career Readiness Standards - Science (6-12)

IOD503: Determine how the values of variables change as the value of another variable changes in a complex data presentation
SIN501: Understand a complex experimental design
EMI603: Use new information to make a prediction based on a model

Next Generation Science Standards (Grades 9, 10, 11, 12)

HS-LS2-5: Develop a model to illustrate the role of photosynthesis and cellular respiration in the cycling of carbon among the biosphere, atmosphere, hydrosphere, and geosphere.

Oklahoma Academic Standards (Biology)

B.LS2.2.5: Extreme fluctuations in conditions or the size of any populations, however, can challenge the functions of ecosystems in terms of resources and habitat availability.

Attachments

- EXPAND-PINEMAP-ARTICLE-Year-3-Annual-Report-Excerpt-TreeTranspirationLesson.pdf
- EXPAND-PINEMAP-Article-Reflection-TEACHER-GUIDE.docx
- EXPAND-PINEMAP-Article-STUDENT-Reflection-Handout - Spanish.docx
- EXPAND-PINEMAP-Article-STUDENT-Reflection-Handout.docx
- EXPLAIN-CER-Statement-Handout - Spanish.docx
- EXPLAIN-CER-Statement-Handout.docx
- EXPLAIN-Transpiration-Video-Guide-TEACHER-GUIDE.docx
- EXPLAIN-Transpiration-Video-STUDENT-Guide - Spanish.docx
- EXPLAIN-Transpiration-Video-STUDENT-Guide.docx
- EXPLOREEXPLAIN-Transpiring-Trees-EXCEL-Instructional-Document - Spanish.docx
- EXPLOREEXPLAIN-Transpiring-Trees-EXCEL-Instructional-Document - Spanish.pdf
- EXPLOREEXPLAIN-Transpiring-Trees-EXCEL-Instructional-Document.docx
- EXPLOREEXPLAIN-Transpiring-Trees-EXCEL-Instructional-Document.pdf
- Evaluate-Control-Celcius.pdf
- Evaluate-Control-Sap-Flow.pdf
- Evaluate-Drought-Celcius.pdf
- Evaluate-Drought-Sap-Flow.pdf

Materials

- Fresh Live Tree Branches, Bradford Pear works well. (1 per group)
- 1 cm graph paper
- #10 Tin Can (1 per group)
- Pruning Shears
- Tape Measure or Meter Sticks
- Graduated Cylinder (1 per group)
- Plastic sheeting (e.g. plastic shopping bag or plastic wrap)
- PINEMAP Journal Article (included) See http://www.pinemap.org/reports/annual-reports/Year_3_Annual_Report.pdf for more information.)
- PINEMAP DATA (Included)
- Microsoft Excel or other Statistical software
- Excel spreadsheet instructions
- CER statement template
- PINEMAP Article reflection sheet

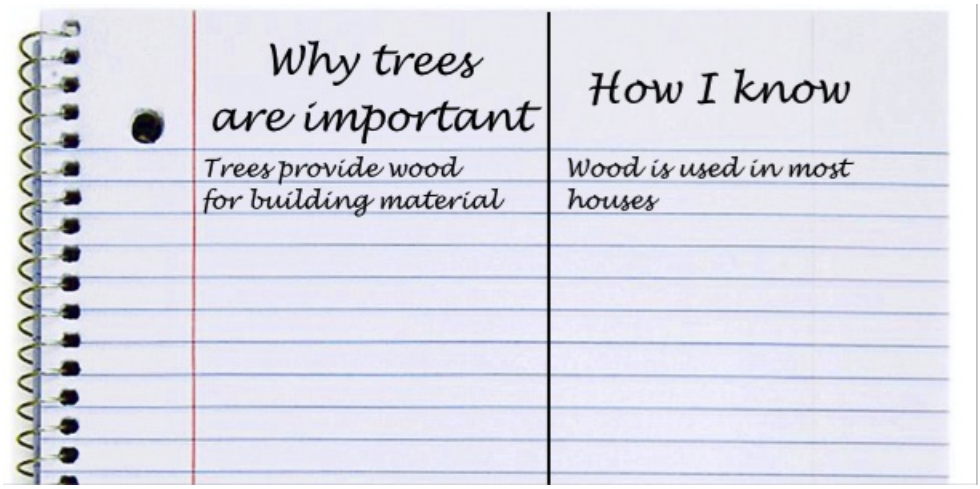
Engage

Show the students the Oklahoma forestry video clip starting at the beginning and ending at time mark 6:50.

Embedded video
https://youtube.com/watch?v=WRp5cMJEGEM

Write the question, "Why are trees important?" on the board. Have the students take a sheet of paper and fold it in half lengthwise to create a two-column page. On the top of the left hand column have them write, "Why trees are important." Have them leave the right hand column blank for now. Instruct the students to individually begin creating a list of all the reasons they think trees are important in the left hand column.

Give the students enough time to generate a good list. Then have the students write, "How I Know It" at the top of the right hand column. For this part of the activity it is sometimes helpful to have the students work with a partner. Have the students write how they know each of the reasons they listed.



Sample "How I Know"

Teacher's Note

This activity helps to engage prior knowledge as well as uncover any misconceptions about the concept. You can use this information to address the misconceptions before beginning the explore phase of the lesson.

Use the round robin process (Have each group share one reasons why trees are important and how they know it, then move to another group. Each group shares a different reason until the most important reasons have been shared.) to have students share out with the class some of the reasons they think trees are important and how they know that information. As students share you can create a running list on the board.

Ask students, "When you buy fresh flowers, what is the first thing you should normally do when you get them home?"

Teacher's Note

Students answers may vary, however if the students don't come up with the answer of cutting the stems and placing the flowers in a vase or glass with water, then provide them with this answer.

Then ask the students, "Why do we put flowers in water?" and "What happens to the water over time? "Where does the water go?

Teacher's Note

Students should state in some form that the flowers need the water to survive and that the water level decreases in the vase because the flowers use the water. The water travels through the flower and is used to make food and some of it exits the plant through the leaves.

Show the students the short video clip "Water transport in trees" (https://www.youtube.com/watch?v=w6f2BiFiXiM).

To wrap up the introduction discussion draw students attention to how trees interact with water in an ecosystem. Students may not fully be aware of the role that trees play in moving water through an ecosystem at this point. Inform students that they will be investigating how trees accomplish the moving of water. Explain to the students that water that evaporates and exits the plant from the leaves is called transpiration.

Explore

PART 1. Investigation Set-Up

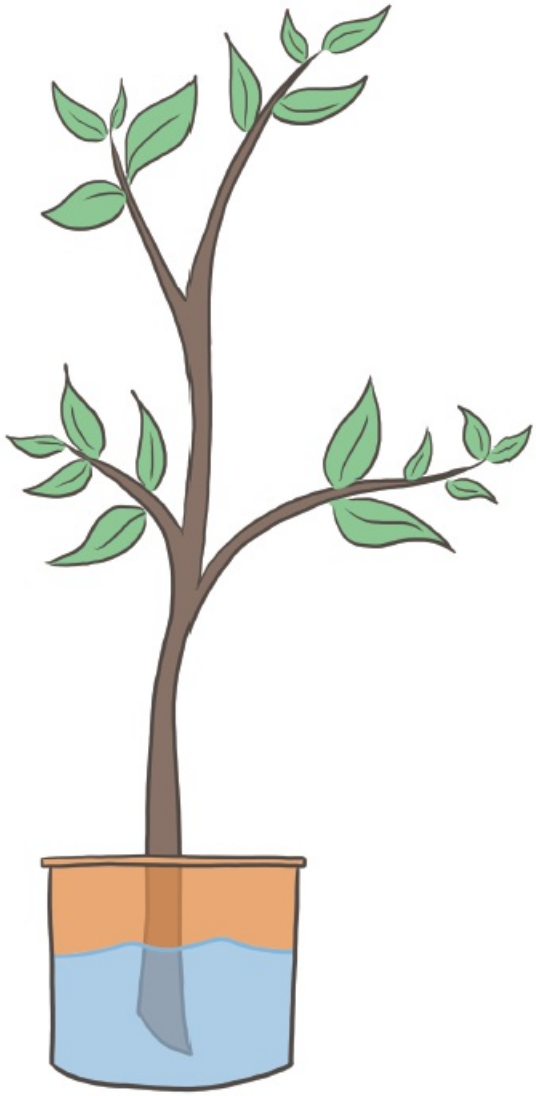
Tell the students that it is possible to do the same thing with trees and tree branches. As a part of the PINE MAP study, researchers are looking at drought and its effect on the growth of Loblolly Pine forests commonly grown for the lumber industry. In this study one thing that is measured is the transpiration rate (amount of water usage) for an average pine tree. One method for measuring this is by cutting down an entire tree and placing it in a bucket of water. The researchers can then measure exactly how much water the tree uses over a period of time (see image below). This is not much different than the setup for keeping Christmas trees alive after being cut down.



Sap flow and transpiration rate data collection (courtesy of Oklahoma NSF-funded EPSCoR's 2014 Summer Authentic Research Experience for Teachers (ARET)

Tell the students that they will be investigating the factors that might be influencing water usage for individual tree limbs using a similar method. Explain to students that each group will receive a live tree branch a large #10 coffee can and the necessary measuring tools.

Show the students the sample set-up below for the investigation. Tell the students, “Before we can begin we need to define the parameters of our investigation. What characteristics of the tree branch could we measure and compare with transpiration rate (water usage) to find possible correlations?”



Sample Transpiration Investigation set-up



Sample Transpiration investigation set-up used by AP Environmental students of 2014 ARET Teacher Participant Bryan Yockers, Jenks High School

Teacher's Note

Students answers may vary, but guide them to three main characteristics: Tree limb length (TLL), Tree limb diameter at can (TLDC), & Total leaf surface area (TLSA). It may take a few questions and suggestion to get the students to identify these three characteristics. Students may suggest the number of leaves. In that case you can ask what would be different between each leaf. Then lead them to the idea that leaf surface area is more accurate. You can use a model such as water being drawn through a pipe or a straw to explain to the students each characteristic. E.g. tree limb length would be the length of the straw or pipe, tree limb diameter would be the size of the pipe or straw, and total leaf surface area would be relative to the amount of force that is applied to draw water through the straw or pipe.

Once the students have identified the three characteristics to use as the independent variables the students will need to create a hypothesis and a null hypothesis for the investigation.

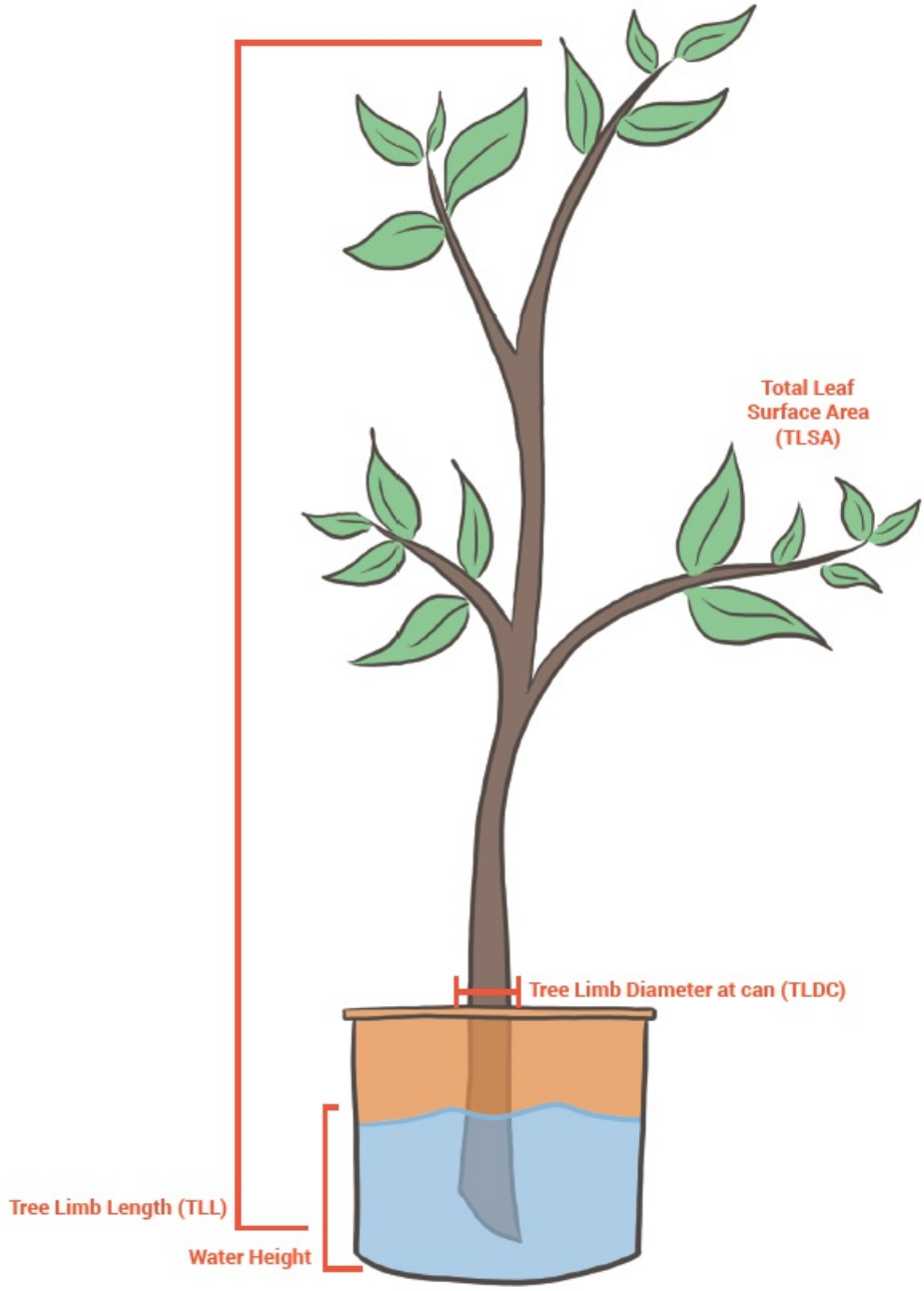
Teacher's Note

Students will have at least two hypotheses. One that states the positive, i.e. what they predict will happen, the hypothesis, i.e. Stem length will have the most significant correlation with tree water usage. A second, the null hypothesis that states the negative, or what they are trying to disprove, i.e. Stem length will not have a significant correlation to tree water usage.

Students will also need to specify how each variable will be measured. This is important because during the data analysis, the class will combine and use all the data collected by the class(es). Consistency in the measurements will lead to a more accurate statistical analysis.

Show the students the suggested measurements methods (See figure below):

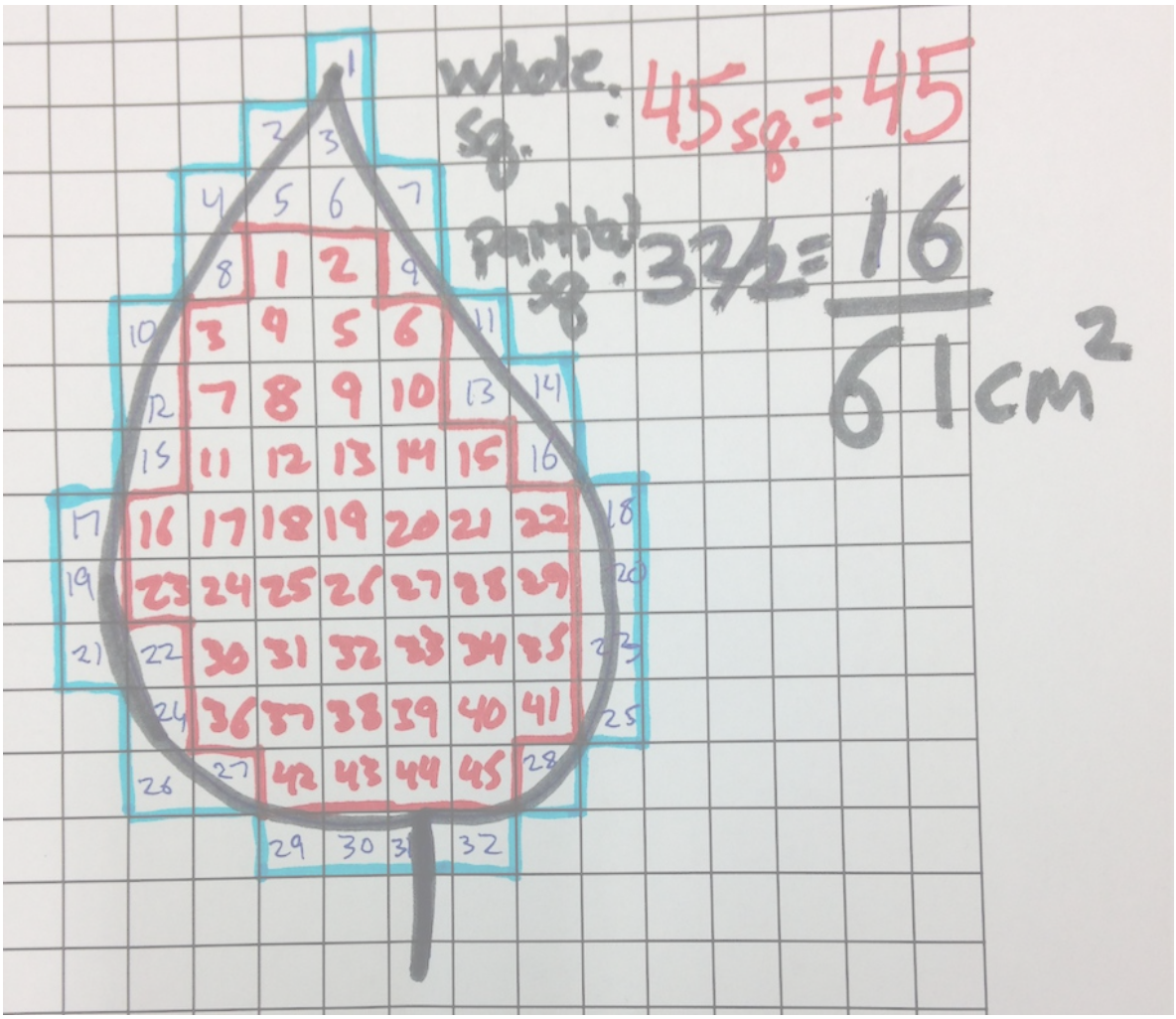
- Tree limb length – Is measured vertically from floor to the top of the tallest point of the limb.
- Tree limb diameter – Is measured directly at the top of the can.
- Total leaf surface area – Will be described.



Sample Transpiration investigation set-up with measurements shown

To measure Total leaf surface area students will need to construct a mathematical model to calculate total leaf surface area. The simplest and most common method for measuring leaf surface area is to use 1cm grid paper.

1. Place leaf on 1cm2 grid paper and trace.
2. Count the number of whole squares covered.
3. Count the number of partial squares covered. Divide this number by 2.
4. Add the number of whole squares to your answer from step 3. This is the surface area of the leaf.



Sample Grid Method for measuring leaf surface area

Even though this method is fairly straightforward is takes time, especially for measuring leaf surface area for an entire tree or tree limb. A second method is to create a mathematical model (an equation) in which you can measure the length of the leaf and input this number into the model and get the leaf surface area for each leaf, then add the surface area together for the entire limb or tree.

To do this you should have 2-3 tree limbs available for your classes. Have each student use the grid method to find the surface area of at least 5 leaves. Students will also measure the length of each leaf. Have the students record their data. Have each of your classes do this. This will provide a large enough data set to enter into the excel spreadsheet (see attached excel spreadsheet instructions document) used to create an accurate mathematical model to utilize during the transpiration investigation. The mathematical model will be unique to the species of tree that you use.

Teacher's Note

By creating a mathematical model it will save your students time during their investigation as well as helping students to gain a better understanding of math concepts and how math and science work together.

PART 3. Transpiration Investigation & Data Collection

Place students into groups of 3-4. Give each group the materials for the investigation.

- Live tree branch
- #10 tin can or similar size container.
- Plastic sheeting

Have students set up investigation as described in the sample set-up figure below. Have students write their group name on the can and place a mark about 3/4 of the way up on the inside of the can. Students will then fill the can with water up to this mark.Next have students use the pruning shears to cut a couple of inches off of the already cut stem while it is underwater inside the tin can (see photometer video).

Embedded video

https://youtube.com/watch?v=qj7jnqgzHuE

Teacher's Note

If the cut is made in air, bubbles will enter the system and shut transpiration down. When preparing and transporting the branches to use in this investigation use the following guidelines:

- When cutting the branches off the trees place them cut end into a bucket of water as soon as possible, however cutting the branches off the trees and getting them into water within 30 minutes shouldn't cause any problems.. You can store them like this for a few days before the investigation in needed.
- A few inches of each transported branch will need to be cut off below the water surface in the trashcan.
- When students begin to set up the system for their investigation, a few more inches will need to be cut off the branch under water in the in the can.

This allows the vascular system, the xylem and phloem, to function properly in regard to water uptake. Have students use a ring stand, table or other available object to attach the tree branch in order to keep the branch vertical.

Have students measure and record initial data. (See Transpiration investigation set up figure above)

Tree limb length (TLL) – Is measured vertically from floor to the top of the tallest point of the limb.

Tree limb diameter at can (TLDC) – Is measured directly at the top of the can.

Total leaf surface area (TLSA) – Have students measure the length of each leaf on the branch and record these measurements in a table. (Students can use a permanent marker to mark each leaf to indicate which leaves have been measured.) Have students figure the surface area for each leaf using the equation created in part 2. Have students add all of the individual leaf surface areas to obtain the Total leaf surface area. (This can be done using a calculator and paper or can easily be setup in an excel spreadsheet to figure the TLSA. See attached excel spreadsheet instructions document.)

Water height/volume - Water height/volume can be measured using two methods.

1. Use a ruler to measure the height from the bottom of the can. Repeat everyday for the duration of the investigation (5-10 days).
2. Place a mark on the inside of the can. Each day of the investigation add water to bring the water level up to the line. Record the volume of water required to “refill” the can to initial level.

Teacher's Note

The branches and can set-up need to be in a controlled environment, e.g. classroom or greenhouse. If placing outside or in a place with automatic sprinklers you will need to use the plastic sheeting to cover the top of the can to keep unaccounted water from entering the system.

Have students record the water used by the tree branch once everyday for the duration of the investigation. The investigation should last at least 5 days but could be longer as more data will result in more accurate analysis. Students can collect data in a journal or a provided data table similar to the table below.

Teacher's Note

You will need to have all of the groups from all classes turn in their data before the next phase of the investigation. During the explain phase, you will lead the students through how to run a statistical analysis on the data using excel (This is a simple process). The larger the data set, the more reliable the results of the analysis will be.

Tree Measurements	Day	Water Height (mm)/Volume (mL)
TLL: _____	1	
	2	
TLDC: _____	3	
	4	
TLSA: _____	5	
	6	

Sample Transpiration investigation data table

Explain

Give students the "?Plant Transport: Xylem and Phloem, Transpiration?" video guide????????????Show the students the short video clip "?Plant Transport: Xylem and Phloem, Transpiration?" (https://www.youtube.com/watch?v=xGCnuXxbZGk). After viewing the video with the students, use the video guide to facilitate a discussion about how plants accomplish transpiration and the plant components that make transpiration possible. ????????????

After the discussion, have the students revisit their hypotheses for the transpiration investigation. Tell the students in order to determine which hypothesis is correct they must analyze the class data using statistical analysis (See excel spreadsheets document). Explain to the students what it means when something is statistically significant and how to determine from the analysis is something is statistically significant.

Teacher's Note

Statistical significance is a mathematical term that describes how sure you are that a difference or relationship exists between variables. The two main statistical measures you can use here are:

1. Correlation coefficient - When analyzing for correlation between variables the R value gives an measure that indicates the extent that variables are related. R values range from 0 to1. The larger the R value the stronger the correlation (e.g. R=.87 indicates a stronger correlation than R=.43).
2. P value – P value is the calculated probability the hypothesis for a given relationship between variables is correct. A p value less than 5% or 0.05 is generally considered statistically significant.

Provide the students with the class data and have the students plot the data on graph paper. Make sure they do not connect the dots, they are creating a scatter plot. It is best to have the students use a separate piece of graph paper for each variable (i.e. Water usage (mL) vs. TLL; Water usage (mL) vs. TLDC ; Water usage (mL) vs. TLSA).

Once the students have plotted the data to create their scatter plots explain to the students how to use a ruler to draw a line of best fit. Explain to the students that the relationship of the line of best fit to the data points indicates if there is a strong relationship between the two variables. By looking at the scatter plots and lines of best fit students should be able to visually predict which relationships are more strongly correlated, however it is necessary to show the students what statistical analysis looks like using excel or other software before they can draw any conclusions.

Teacher's Note

It is recommended that you have the class data entered into an excel spreadsheet already. Follow the instruction on the excel spreadsheets instructions document to enter and run the appropriate statistical analysis.

Show the students the results of the statistical analysis. Be sure to point out the R value and the P value for each set of data if possible. Ask the students to interpret the R value and P value for each data set and determine which relationship had the strongest correlation and which had the weakest correlation.

Teacher's Note

You should find that the TLSA had the strongest correlation (R value) and the most statistical significance (p value).

Have the students write a short conclusion for the transpiration investigation using a CER Statement.

Write a Scientific explanation to answer the question: What characteristic of trees has the greatest impact on water usage and transpiration rates of trees?
Claim (Write 2-3 sentences that state what characteristic of trees has the greatest impact on water usage and transpiration rates of trees.)
Total leaf surface area had the greatest impact of the transpiration rate of our tree limbs. Tree limb length and Tree limb diameter had little to no effect on the water usage and transpiration rate of out tree limbs.
Evidence (Provide data that supports your claim about what characteristic of trees has the greatest impact on water usage and transpiration rates of trees.)
When we added lines of best fit to our scatter plots the TLSA vs. water usage appeared to have the closest relationship. The correlational analysis of our data showed that TLSA vs. water usage were related at an R value of 0.85 and had a p value of 0.02. The correlational analysis for the other variables were not significant. The R value for the TLL vs. water usage was 0.53 and the p value was 0.7 and the R value for the TLDC vs. water usage was .68 and the p value was 0.2.
Reasoning (Write 2-3 sentences that connect your evidence to your claim about what characteristic of trees has the greatest impact on water usage and transpiration rates of trees.)
Among our three variables (TLSA, TLL, and TLDC), TLSA had the strongest correlation to water usage. This show us that the leaf surface area has an effect on the amount of water use by a tree and how much water is lost through transpiration out the leaves.

Sample student CER statement

Extend

Give each student a copy of the article "Using the Tier III Experiments to Investigate the Effects of Drought and Fertilization on Forest Water Use and Stomatal Conductance." Have the students use an analytical reading strategy such as Why-Lighting to do a close reading of the article. Make sure students are aware and looking for familiar words related to the transpiration investigation such as: Stomata, transpiration, carbon dioxide, photosynthesis, etc..

Hand the students the article reflection sheet and have them answer the questions from their reading and Why-Lighting notes. Give the students time to complete the reflection sheet. After the students finish the reflection sheet have them get in groups of 2-3 to discuss what they read and how they answered the reflection sheet.

After a few minutes of small group discussion, post the following question on the board for the students to see: "What similarities and differences exist between the large scale PINEMAP research study and our transpiration investigation?" Have the students write a GIST statement (summary statement in 20 words or less) to answer the question. After the students have finished their statements have each group share their response.

Evaluate

Provide students with the sap flux data from the PINEMAP research study. This will include sap flux data for 2 plots of trees (control – regular rainfall and drought – 30% less rainfall)(see plot map below). Explain to the students that the sap flux data is a measure of the temperature difference in the probes and this difference is caused by sap flow in a tree. This measurement can be used to calculate sap flow and therefore water usage/transpiration rates for the tree.

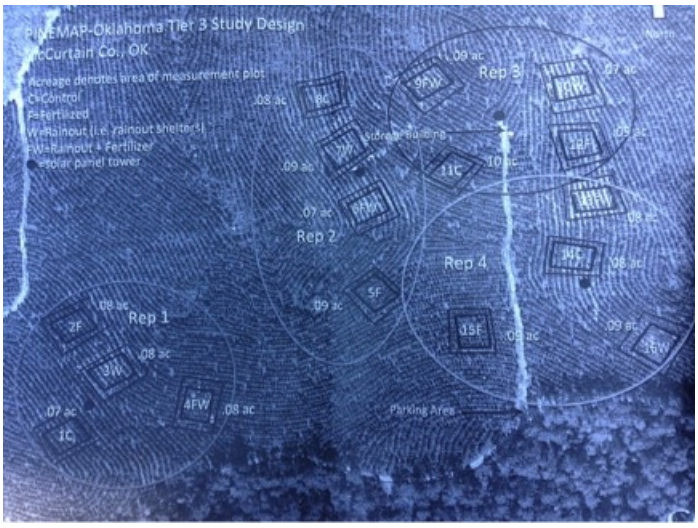
Teacher's Note

Show the students the pictures below of the sap flux sensors and the video explaining how the probes are used (http://www.learner.org/courses/envsci/unit/text.php?unit=8&secNum=1 from 8 minutes to 9:30 minutes). You can also use excerpts from the original article describing the use of the thermocouple probes. The article is rather complex, so just introduce the main ideas.

Have students analyze the data in terms of transpiration rates and using their analysis have them draw conclusions about the transpiration rates of the tree on the four different test plots. Have students explain the daily patterns seen for probe temperature difference and sap flux data.

Teacher's Note

Have the students write a CER statement for each set of data. Have students turn in their data analysis and the CER statements. Students will then turn and talk with and “elbow partner" to discuss their analysis and data interpretation. Students will finally form a few larger groups, which will informally present their final ideas/findings to the class for discussion. Afterwards, students will be able to add a new revised "CER" to their submission.



PINEMAP Tier III research plot map



Rainfall excluders on drought plots carry 30% of rainfall off of the plot to simulate drought



Sap Flux/Flow sensors used to measure sap flow and water usage in a tree

Resources

- K20 Center. (n.d.). How I Know It. Strategies. https://learn.k20center.ou.edu/strategy/144
- K20 Center. (n.d.). Claim, Evidence, Reasoning (CER). Strategies. https://learn.k20center.ou.edu/strategy/156
- K20 Center. (n.d.). Gist. Strategies. https://learn.k20center.ou.edu/strategy/3289
- K20 Center. (n.d.). Why-Lighting. Strategies. https://learn.k20center.ou.edu/strategy/128