planting science

The Tree-mendous Benefits of Trees:
An introduction to trees and scientific observations

Teacher's Guide

Overview

Premise: Trees are an important and recognizable part of landscapes and forests, but most people don't think about the importance of trees and their value to the landscapes. Furthermore, most people don't notice the condition of trees – that is, whether the trees are healthy, diseased, or in a state of decline – but tree health is crucial to a landscape.

Why is all of this important? Trees add beauty, but they also contribute shade, help mitigate stormwater runoff and soil erosion, and improve air quality by providing oxygen, filtering out particulates in the air and storing carbon. Trees also provide food (fruits and nuts, for example) and are home to wildlife, fungi, insects and microorganisms.

However, optimal benefits come from large, healthy trees. Many things can impact the health of trees in an urban setting. The wrong planting location, poor soil conditions, drought or flooding, not enough or too much sun, wounding, and diseases and insects are some of the things that can cause tree decline. The mortality rate for urban trees is very high – some studies suggest that "40-60% of urban trees die within the first 10 years," (Ness 2015).

Teacher's Guide

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The value of trees. How do we place a "value" on trees? Examining and quantifying tree health can be a challenge, but it's an important question. City managers, homeowners and property owners must make important economic decisions on whether to purchase and add trees to a landscape and cut down unhealthy trees.

It is hoped by through this activity, students will become more aware of the condition of plants in their surroundings. More specifically, students will learn to

1) recognize visible indications of healthy versus unhealthy trees,
2) collect data and make observations to assess tree health, and

3) use an online tree benefit calculator to approximate the benefits, in dollars, of their selected trees in terms of stormwater mitigation, property value, energy savings, air quality, and atmospheric carbon.

How *The Benefits of Trees* Module works:

This module contains guidelines for developing research or inquiry-type questions pertaining to tree health in an urban setting - on the school grounds, in a garden, yard or landscape. We encourage teachers to incorporate a section of the school landscape as part of the study, but students can also be directed to evaluate trees at home or another off-campus site.
Beyond the lab investigations, three other types of activities are essential to fully benefit from this module:

- **Classroom discussion**: authentic classroom dialogue before, during, or following lab activities
- **Research Blogs**: regular online contact between students and scientist mentors and peers
- **Storyboard discussion**: an extended post-lab discussion in which students share and reconcile data within and across teams.

We have found that a teacher's commitment to dialogue and a focus on student ideas and reasoning emphasizing the process of science is an important aspect of building an open culture for science learning. Explanations using everyday vocabulary are valued over use of scientific vocabulary in the absence of explanations. A more detailed description of teaching and learning strategies used in the module can be found in the PlantingScience Teacher's Handbook.
Grade levels: High school—biology, AP biology, environmental science, AP environmental science, horticulture, botany, and other life science electives.
Class time: Students should be able to complete the thought investigations, the two guided inquiries, and the open investigation over a two- to three-week period. During that time period, there will likely be time that can be used for other aspects of your curriculum. For example, when students are waiting to hear back from their mentors, you can fill that class time with other lessons from your standard curriculum.
Computer access: Optimally, every other class session outside of the open-inquiry period and daily while designing the open inquiry; minimally, at least three times over the course of the full investigation period. Team blogs require logins.

Planning

Suggested Schedule of Activities:

Research questions can be centered on evaluating or comparing the condition and health of selected trees. To investigate these questions, hands-on activities can include collecting data on tree size, shape, and qualitative and quantitative observations as part of a tree health report. Data collection for this module is similar to an urban tree survey used to assess "tree health."

Suggested Assessment Schema:

This module is designed so that students can be assessed continuously for changes in understanding. Classroom discussion, teacher interactions with teams during lab investigations, science notebook entries and drawing, and blogging online can all serve as embedded formative assessment tools. The post-lab class Storyboard Discussions, a final individual reflection, and the post-experience survey serve as summative assessment tools. If desired, summative assessment in an exam format could involve written responses to questions such as the following:

- Why are trees beneficial to our landscapes and cities?
- What characteristics are important in determining the value of a tree?
- What are some indications of good tree health? Of poor tree health?
- What can we do to maintain tree health?

Additional Resources:

The appendix contains a bibliography of websites and articles pertaining to tree health.
You can expect to complete *The Benefits of Trees* module over the course of 2-3 weeks. During this time, you can intersperse *The Benefits of Trees* activities with your normal classroom curriculum. For example, you may want to allow 2-3 days between when students contact their mentors and when you would begin the next activity in *The Benefits of Trees*. This would enable students to get the benefit of working with their mentor before beginning the next step in the module.

Please let your scientist mentor(s) know

- which lessons you will be implementing;
- your expected start and end dates for interacting with students online;
- how frequently your students meet;
- the tentative dates for when students will be communicating with mentors;
- a brief summary of what students should know about plant diseases, plant physiology, and scientific inquiry;
- any special experiences or challenges that the students may have with respect to completing these activities;
- a brief description of the laboratory equipment and supplies available to your students
- how often students will have computer access.

Open Inquiry

Overview

The aims of this module are to encourage students to become more aware of the plants in their city landscape, understand the importance of trees and tree health, connect observations about plant growth and form with function, and connect tree health data and observations with the benefits and value of trees in a landscape.
Students should work in teams of 3 to 4, and individual team members are encouraged to post online and communicate with their mentors about their observations.

Time Required (Suggested)

- **Days 1-2**: Opening discussion, brainstorming.
  Introduction to concepts of tree health and tree benefits (to accompany classroom lessons in plant biology or related topics). Students write introductions to their mentors (First names only, interests – hobbies, favorite subjects, etc.).
- **Days 3-4**: Conduct an outdoor walk on the school grounds to take some initial observations on the trees and landscape. Demonstrate how to take tree diameter measurements. In the classroom, have students discuss and develop ideas for their inquiries and projects. Students share their ideas with their mentor and finalize their research question. Post their question on their project page on the PlantingScience platform.
- **Days 5-6**: Project. Allow at least 1-2 class periods for students to take tree measurements and collect data outdoors; try to identify trees in their study site (allow for flexibility if weather is an issue).
- **Days 7-9**: Examine and discuss the data collected; calculate tree benefits; conduct additional research using websites/books on the trees in their study. Present data in graphs, tables and infographics; compile final reports.
- **Storyboard discussion, project page updates**: Optimally, you will schedule this lesson so that scientist mentors have time to respond to team blog posts before the students move on to their next step. The goal is for students to get feedback from mentors and be able to incorporate that feedback before moving on. Therefore, it is likely that the days for this investigation will not be consecutive class periods.

The Benefits of Trees can be completed in two weeks of class time, with the idea that you will intersperse these activities with your normal classroom curriculum. Try to schedule this lesson so that scientist mentors have time to respond to team blog posts before the students move on to their next step.

Communicating with Your Mentor

Allow time for students to communicate with their scientist mentor online. If not already acquainted with the mentor, students should introduce themselves and their teammates and ask some general questions. If they have already sent their mentor a message, ask them to check to see if they have heard back from their mentors.

Please let your scientist mentor(s) know:

- which lessons you will be implementing;
- your expected start and end dates for interacting with students online;
- how frequently your students meet;
- the tentative dates for when students will be communicating with mentors;
- a brief summary of what students should know about plant diseases, plant physiology, and scientific inquiry;
- any special experiences or challenges that the students may have with respect to completing these activities;
- a brief description of the laboratory equipment and supplies available to your students;
- and, how often students will have computer access.

Students should work in teams of 3 to 4, and individual team members are encouraged to post online. In the *Student's Guide*, the image at right indicates opportunities for Research Blogging. Teams may blog from school or from home.

Learning Goals

Student should be able to:

- Describe the role and function of trees
- List the benefits of trees in a city
- Describe observable characteristics of healthy and unhealthy trees
- Formulate a research question and determine the data and information needed to investigate the question
- Take measurements and make observations that are important in evaluating tree health
- Be able to use an online Tree Benefit Calculator to estimate benefits such as stormwater mitigation, property value, energy savings, air quality, and atmospheric carbon reduction

Common Misconceptions and Student Biases

- Lack of awareness that plants can get sick or wounded
- Lack of knowledge about the wide range of benefits associated with trees

Getting Ready

Student's Guide Section and Resources

The information in this section mirrors the information in the Student's Guide available online here.

Materials and Supplies

*Students should work in teams of 3–4 for this investigation.

1. Safe access to school grounds or an outdoor site with several trees
2. Computer and internet access
3. Notebook and pencil
4. Measuring tape to measure tree circumference (alternate: string or yarn)
5. Ruler
6. Calculator
7. Graph paper or computer software (e.g. Excel) for data analyses
8. Websites and books on tree identification (public library is a good resource)
9. Optional: magnifying glass
10. Optional: camera

Preparations

- Review the student and teacher procedures for the lesson.
- Gather a range of materials that students may use for their investigations.
- Students will post to their blog and receive feedback from their scientist mentors on their investigations at several points during this activity. Communicate with the mentors ahead of time to let them know when to expect blog posts and to find out how quickly they will be able to provide feedback. This information will help you schedule class time for completing the open-inquiry investigations.

Procedure

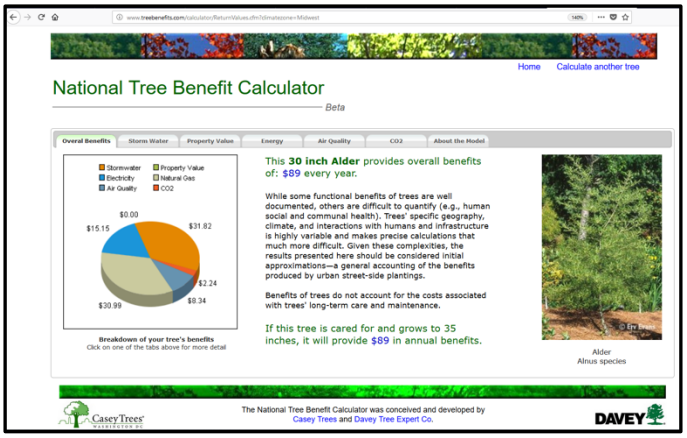
Procedure Note to Teachers: The procedure that follows provides a framework for using this lesson in the classroom. However, you should feel free to modify it based on your students' prior experiences, knowledge, and abilities. The step numbers listed in these procedural steps match those in the student pages.

1) **Communicate with mentors ahead of time.** Teachers - communicate with the mentors ahead of time to let them know when to expect blog posts and to find out how quickly they will be able to provide feedback. This information will help you schedule class time for completing the open-inquiry investigations. Students will post to their blog and receive feedback from their scientist mentors on their investigations at several points during this activity.

2) **Select an outdoor site with several trees that is in a safe, accessible area for students.** The module is intended for students to analyze a group of trees that are easily accessible on the school grounds (or in their neighborhoods). Each group of students may aim to collect data on 5-10 trees in 1-2 class periods. To expand the study, additional class periods can be devoted to outdoor data collection and observations. Areas with trees of various ages and sizes will generate some interesting comparisons. It may also be interesting to incorporate new plantings with older, established trees on your school grounds.
    a. It will be helpful for students to be able to identify tree types (e.g. maple, pine etc.), and this could be a focus of the module. If it isn't possible or beyond the scope of your class, you can still do the module and use the online Tree Benefit Calculator. Online tree identification resources and books can be used to help identify tree types at the level of genus – e.g. maple, oak, pine etc. Libraries often have books that can help identify trees for your region. Your PlantingScience mentor is another important resource for your students. *(More resources are listed at the end of this document: "Additional Web Resources for Doing Research in the Field.")*
3) **Become familiar with standard tree measurements:**
    a. **Tree diameter (4.5 ft above ground).** Tree diameter, often called tree breast height, is a common measurement of tree size for tree surveys. Tree diameter can be used to estimate tree volume or tree age, and a tree's diameter can be compared over a period of years to determine growth rate.
    b. Encourage students to take multiple measurements (minimum 3) for a given tree to establish consistency in taking measurements. The National Tree Benefit Calculator is based on tree diameter measurements in ***inches***. Ask students why it is important to take multiple measurements (hint: to ensure consistency and avoid large errors in measurements). The measurements for each tree can then be averaged.
4) **Calculating tree diameter by measuring tree trunk circumference**:
    a. Using a ruler or measure tape, determine the point on the tree trunk 4.5 feet from the ground.
    b. Measure the circumference of the tree trunk at the 4.5 foot mark with a measuring tape (inches). Alternatively, students can use a piece of string or yarn to determine the diameter of the tree, and then measure the length of the string.
    c. Calculate the tree diameter with the following formula:

$$\frac{Tree\ circumference\ (inches)}{\pi\ (3.14)} = Diameter\ (inches)$$

5) **Troubleshooting. What about odd shaped trees?** The following website has some good diagrams of the process, as well as instructions for measuring trees on a slope, multi-branched trees and trees with unusual forms:
    a. City of Portland, How to Measure a Tree www.portlandoregon.gov/trees/article/424017
    b. Portland Parks and Recreation, How to Measure Trees: youtu.be/R9eQ9qFrSVs
    c. **Tree height (optional)** Students can measure tree height with a yardstick based on principles of geometry. Although this measurement is not needed for the Tree Benefits Calculator, it can be interesting to investigate whether tree height is correlated with tree benefits. Several websites describe how to measure tree height with a ruler or yardstick; this video from the Stephen F. Austin State University has a good demonstration that doesn't actually require that the students knows geometry: youtu.be/cDy5OjfMfZ8.
6) **Use the National Tree Benefits Calculator website:** www.treebenefits.com/calculator/
    a. To use the Tree Benefit Calculator website, you will need to enter a zip code. Alternatively, you can select a zone from the U.S. map in the link provided (www.treebenefits.com/calculator/mapselect.cfm) to explore another part of the U.S. Or use https://www.itreetools.org/ to explore international sites.
    b. Input examples into the Tree Benefit Calculator. Using the drop-down menus, select a tree species ("Unknown" is an option), tree diameter (4.5 feet from the ground), and the land-use type (e.g. residential, small or large commercial business, etc.). To test the site, you don't need actual data, you can try different tree species and numbers.
    c. For a school yard, for the land-use type, you may want to select either the small or large commercial business, or a park. Use your judgement to determine what best describes the setting for your site.
    d. The tree calculator will give you an output for each of the following parameters:
        i. Storm Water (gallons of stormwater runoff intercepted)
        ii. Property Value (in dollars)
        iii. Energy (kilowatt hours of electricity)
        iv. Air Quality
        v. CO_2 (reduction in atmospheric carbon)
    e. For each of these parameters, read the explanations on each tabbed webpage. You can adapt the use of this information to your class. Explain to the students that these benefits are approximations, not exact amounts.



Suggested Schedule of Activities

Week 1 (1-3 class periods)

1. **Discussion: Plant Biology**. Lessons and discussion about the function of leaves, stems and roots in plants that are a part of the existing curriculum.
2. **Discussion: Benefits of trees.** Have the students list as many benefits of trees they can think of. There may be more benefits than listed here! *(The National Tree Benefit Calculator's – analysis of results provides good explanations of the benefits marked with an asterisk below)*
    a. Beauty
    b. Biodiversity: trees provide habitat and food for insects, wildlife, birds, fungi and other organisms
    c. Food for humans (fruits, nuts)
    d. Medicines, for example:
        i. Salicylic acid, or aspirin, from the willow tree (*Salix*)
        ii. Quinine, used to treat malaria, from the bark of the cinchona tree
        iii. Taxol, used to treat cancer, from the bark of the Pacific yew tree
    b. Wood for lumber (housing, furniture, buildings)
    c. Other uses of wood: paper, pencils, baseball bats; violins, guitars
    d. *Property values (trees can raise the value of property and homes)
    e. *Shade, which can impact Energy usage (reduce heating costs for buildings)
    f. *Intercept stormwater runoff (from rain) and reducing soil erosion
    g. *Air quality – trees can absorb many pollutants and filter small particulate matter (dust, ash, smoke); produce oxygen through photosynthesis
    h. *Reduce atmospheric carbon – trees can incorporate, or sequester, carbon dioxide in their plant tissues. In addition, by providing energy savings, trees can help reduce emissions associated with energy and power production.
    i. *Tree value (an estimation, in dollars)
3. **Tree Health Discussion**. A discussion about tree health be connected to a discussion about human health. Plants can get diseases, be infested with insects, and suffer wounds.
    a. Trees can also be impacted by drought, flooding or water-logged soil conditions, road salt, high and low temperatures, and too much or not enough sun. For an interesting article on the topic of tree health, read, "Getting to the root of urban health" (dl.sciencesocieties.org/story/2015/dec/thu/getting-to-the-root-of-urban-tree-health).
    b. Ask the students what the impact on tree benefits might be if trees are sick or unhealthy. This can include the cost of removing or cutting down sick or dead trees that might pose a safety hazard in a city or public space.
    c. For many plants, there are few options once a plant gets a serious disease or insect pest. If the problem isn't too bad, it may be best to do "nothing" as the tree may be able to tolerate a low level of disease.

d. Discuss and show photos of common examples tree stress or damage:
    i. Dead branches, dead wood (many causes: injury or wounds caused by humans, wind, snow, or insects, diseases)
    ii. Leaning tree trunk
    iii. Broken branches
    iv. Wounds (cankers) in the bark or cracks in the bark
    v. Exposed roots (possibly caused by improper planting or bad planting site; sidewalks or other impediments to tree growth)
    vi. Suckers at base of tree (general indication of tree stress)
    vii. Damage from equipment
    viii. Vandalism (graffiti)
    ix. Animal damage
    x. Condition of the leaves: dying leaves or needles, spots or lesions (dead areas) on leaves (examine healthy leaves; note that leaf color may depend on the time of year or season. It is imperative to determine what a "healthy" leaf looks like.

e. **Other organisms**
    i. Other organisms associated with trees insects or indications of insect damage, birds, mushrooms on or around the tree, lichens on the tree bark, galls (tumor-like growths caused by insects or other organisms). These organisms may or may not be beneficial or harmful to the tree.

f. **Other notable observations:**
    i. Rotted tree parts, evidence of decay
    ii. Mistletoe, vines, or other plants growing on the tree

g. **Resources**:
    i. Forest Health Detectives, an Inquiry and Investigation by Tara L. Bal, published in the American Biology Teacher (Vol. 76, Oct. 2014) has good diagrams and photos, as well as ideas for research investigations and data collection.
    ii. Diagnosing Sick Plants, Ohio State University Extension, by S.D. Williams, M.J. Boehm, J. Chatfield, J. Boggs and E. Draper. ohioline.osu.edu/factsheet/plpath-gen-2

4. **Invasive Species Discussion (optional)**
    a. Pest and Disease Alerts in your State. Have students do some internet research about trees in your region. Extension or Department of Agriculture websites in your area or state may also have notices about tree diseases or insects to be on the lookout for.
    b. Resource:
        i. USDA Animal and Plant Health Inspection Service, Hungry Pests website: www.aphis.usda.gov/aphis/resources/pests-diseases/hungry-pests/
        ii. These are good resources on invasive species (mostly insects) affecting plants in the U.S.:
            1. View videos, Meet Vin Vasive: a series of 30-second videos that illustrate how invasive species can be moved by humans

2. The Threat – A listing and information on Top Invasive Pest Threats
3. What You Can Do – tips that we can use to prevent movement of invasive species on plants through travel and outdoor activities

iii. Encourage your students to ask their PlantingScience Mentors if they are aware of any invasive pests or diseases of trees in your area. Although you may not find these insects or diseases on trees at your school, it is good to be aware of these problems.

End of Week 1 through Week 2

5. **Outdoor demonstration**. Take the class outdoors on a "tree walk" to examine the area. With a selected tree, demonstrate how to measure tree diameter (as described below)
6. **Formulate the research inquiry and experimental design; collect data**. Encourage your students to formulate questions about the condition of the trees in their school grounds, and then determine what data and information should be recorded for the analysis. Both qualitative and quantitative data should be collected. Some prompts are listed below:

Possible questions and inquiries	Comments; suggestions for data collection, reporting and evaluation
What kind of trees in the study area offer the most and/or least landscape benefits?	Students can research the landscape benefits of the different tree species (e.g. shade, size, leaf color, blossoms, insect and disease resistance, adapted to your climate, tolerates road salt, etc.
How do trees in the study area contribute to local biodiversity?	Students can list and describe any organisms on or around the trees that were found and research (internet, books) to learn more about the types of wildlife, birds, fungi and insects associated with your tree species (it may be impossible to observe birds, squirrels etc. depending on the time of year). Information can be presented in an infographic or chart.
What are observable indications of healthy trees compared to unhealthy trees in the study site?	Create an infographic, drawings or photo collage of observations.
What is the percentage of healthy trees compared to unhealthy trees?	Calculate percentages and graph data and comment on any patterns in tree health within the study area.
Is there a relationship between tree size and tree type? E.g. Storm Water (gallons of stormwater runoff intercepted), Property Value, Energy, Air Quality, Atmospheric Carbon, and Tree Value ($)	Data can be presented in a graph or table. Students can discuss the costs-benefits of trees in a landscape.
What can be done to improve the management of trees? What should be done with sick or dying trees?	Students can research tree care options, including the cost of pruning or cutting down trees. Depending on the location/ownership of the trees, investigations comparing treatments could be done.
Taking into account costs, benefits, and location constraints, what trees would you recommend planting if you were managing the landscape of the study area?	Students can search local nurseries on the internet to determine the cost of purchasing a tree. Students can also try to estimate how many years until the stand is established. How can this information be used by the school to make decisions on whether to purchase and plant more trees?

Additional Resources

- S.D. Williams and M.J. Boehm. Plants Get Sick Too! Ohio State University, Ohioline online fact sheet: ohioline.osu.edu/factsheet/plpath-gen-1
- E. Ness. Dec. 2015. Getting to the Root of Urban Tree Health. *CSA News*. dl.sciencesocieties.org/story/2015/dec/thu/getting-to-the-root-of-urban-tree-health

Storyboard Discussion

What is the purpose of a storyboard?

Storyboarding consolidates "the evidence" so students can consider how their data fits into their models of photosynthesis and cellular respiration. By **sharing** their stories and allowing other students to **question** their conclusions in light of data, observations, experiments, or everyday and school science experiences, students learn to **reconcile** evidence as scientists do. This process is sometimes referred to as **scientific thinking**.

Preparing storyboards

A storyboard consists of the following elements:

- Research question
- How students investigated the question
- How students know the experiment was technically successful (i.e., the method worked)
- Data summaries
- What the data mean
- A model of how tree health impacts function in terms of growth and photosynthesis, and how the data fit the model
- Data from class or other teams' experiments that are or are not consistent with their explanations and model. During this guided inquiry, students may make team storyboards if there is time. Each team can present their "story" to the whole class, then answer questions from the class. Alternatively, the teacher may diagram the processes described by students as their ideas about tree health, tree growth and function. As the teacher models how a storyboard is constructed, students can see how to make their own team storyboards after their open- inquiry experiment(s).

Integrating writing and discussion

Students should be encouraged to diagram on paper to develop and supplement their explanations. Diagramming can be a good shorthand for students to get their working ideas on paper—scientists often use this approach, too! If students are not used to sketching out their thoughts in pictures, teachers can model this by drawing pictures as the class develops a working model.

The questions that students answer in their science notebooks during this investigation are only a guide. If students think other information should be recorded or if a drawing or diagram would help, they should be encouraged to add these items.

If poster-sized whiteboards are available for each team, a large erasable working surface can be helpful as students work through their thinking as a team. Their final "story" can then be presented from the whiteboard.

Storyboard Discussion (cont.)

Juicy questions	**Additional information can be found in this series:**
1) How would a disease or insect that damages the tree leaves impact its growth? 2) How would poor root growth impact the tree? 3) If you were asked to decide if the school should plant more trees, what information would be helpful in making these decisions? 4) Also consider the areas where the tree(s) will be planted, or the site selection. Teams should be able to use their observations from the guided inquiry and the Tree Benefits Calculator to help answer this question.	• E. Macie, S. Workman, H Campbell. 2016. Urban Tree Planting (Part 1): Site Selection. eXtension.org. articles.extension.org/pages/67466/urban-tree-planting-part-1:-site-selection • E. Macie. 2016. Tree Planting in Cities (Part 2): Site Preparation. eXtension.org. articles.extension.org/pages/73692/tree-planting-in-cities-part-2:-site-preparation • E. Macie, S. Workman, L Morris, H. Campbell. 2016. Tree Planting in Cities (Part 3): Tree Selection & Planting Guidelines. eXtension.org. articles.extension.org/pages/67409/tree-planting-in-cities-part-3:-tree-selection-planting-guidelines

Storyboard Discussion (cont.)

The goals of the guided inquiry lab are:	Key questions
• Learn about the role of trees on earth • Learn the benefits of trees in a city • Describe observable characteristics of healthy and unhealthy trees • Formulate a research inquiry and determine the data and information needed to investigate the inquiry • Take measurements and make observations that are important in evaluating tree health • Be able to use an online Tree Benefit Calculator to estimate benefits such as stormwater mitigation, property value, energy savings, air quality, and atmospheric carbon reduction	• What constitutes evidence? • How do the group's data fit into its own model of tree growth and function? • In what ways is the method limited? • Can the method be improved? • How is the age of the tree related to the benefits produced by the tree?

Product

At the end of the discussion, the class should arrive at a consensus model for tree health, tree growth and tree benefits.

Procedure Note to Teachers:

The procedure that follows provides a framework for using this lesson in the classroom. However, you should feel free to modify it based on your students' prior experiences, knowledge, and abilities.

Follow-up Steps:

1) Ask students to share what they have learned from the previous lessons. If the class has been completing the storyboard, take time to review the progress. Introduce students to the idea that this time they will be developing their own research question and then planning and conducting their own investigation to answer the question. Allow time for students to read through all the procedural steps in their student guide for this investigation.
2) Introduce students to the *Student Roadmap Through an Investigation* resource (plantingscience.org/studentdoingscience) on the PlantingScience website. Students should refer to this resource at various times during their investigations for guidance.
3) Students should begin thinking about what interests them about plant diseases. Instruct students to read through the information found at the *Explore Your Topic* link in the *Student Roadmap*. Students can spend some time individually thinking about their interests. If, during previous investigations, they wrote ideas for future investigations, they can refer back to those now. After working individually, teams can start discussing their ideas together.
4) During these steps, students read information about testable questions in their procedure and in the *Research Question* section of the *Student Roadmap*.
   If helpful, hold a brief discussion about testable questions before students move on to the next step.
5) Allow time for teams to work together to come up with 2–3 potential research questions to investigate. For each of their ideas, they should write answers to the questions listed in this step.
6) The questions should help students think more about their research questions and the possible investigations they would do. Because students will share this with their mentors, the questions also provide a framework for presenting ideas to the mentors. As teams are working on their research questions, they may have questions and need more information. Include links to this information here.
7) One consideration related to potential research questions is relevance. Will this research question investigate something that has a real-world connection? For example, a common idea for student investigations is to see what happens to plant growth if they are watered with cola. Such a research question doesn't have a strong connection to real-world plant biology. Another problem with such investigations is that these beverages are complex mixtures of chemicals and vary depending on bottler, brand, and flavor. It would not be feasible in the classroom to identify which component of the beverage produced an effect. As the teacher, you can watch out for questions such as this, and the mentors will also provide feedback if students present a flawed research question.

8) Teams should take pictures of their notebook pages with information about their brainstormed research questions and their responses to the Step 5 questions. Teams can upload these photos to their project page on the website for their mentor to view.
9) Each team should work together to reach a consensus about which information should be presented to the scientist mentor.
10) After receiving feedback from their scientist mentor, each team should narrow their focus and decide on a single research question that they will investigate. Teams should add information and suggestions from their mentors to their notes from Step 6.
11) The feedback that teams get from their mentors can help identify potential problems or provide suggestions for how teams can strengthen their research questions.
12) Allow time for students to read the *Planning Your Study* section in the *Student Roadmap*. This information provides guidance on matching the experimental method to the research question as well as developing research and data collection plans.
13) Allow time for teams to work on their experimental design for their chosen research question. The questions listed in the procedure should help teams think through details about their experiment. Encourage students to check with you about materials or supplies that they may want to use. If certain supplies are not available, they may need to modify their design.
14) After teams agree on their experimental design, they should post pictures of their notebook pages with details of their design for their mentors. Allow time for mentors to review the experimental designs and provide feedback before moving forward with the investigations.
15) Allow 2-3 class periods (45-minute periods—or perhaps 1 block schedule period) for students to conduct their investigations (after incorporating feedback from mentors). Be clear with students as to how much time they have to complete their investigations. Teams may need guidance about fitting their investigation into the available class time. For example, they may need to figure out whether they can complete their investigation in 1 day or whether they need to think about how they could do part on one day and the rest on the next day. If necessary, help students identify appropriate stopping points in their procedure. Teams may need to spend some time testing parts of their procedure before beginning their real investigation. Encourage them to ask questions of their mentor if they run into problems.
16) Allow time for teams to work on the analysis of their data. Encourage teams to think about the best ways to summarize their data. Sometimes, a photograph works well. In other cases, they may need a graph or diagram. Often, they may want to use multiple formats.
17) Teams should work together to make sense of their results. The questions listed with Step 12 should help guide students' thinking and help them present their results to their mentors. When teams are ready, they can take pictures of their notebook pages and upload them for mentors to review and discuss. Optimally, you will allow time for mentors to view blog posts from students and give their feedback. Teams may want to discuss the feedback with the mentors before moving on with the rest of the investigation.

18) Ask teams to create a presentation about their investigation and the results. Explain your preferences regarding presentation format and time. For example, do you want students to prepare posters or PowerPoint presentations?
19) Have each team present its research question and experimental results with the class. As teams present, discuss how these results add to the storyboard that the class has been developing and how they are consistent (or inconsistent) with the results of other teams. Discussing how different investigations adds to students' knowledge of photosynthesis and plant growth helps students fit their experimental results into a larger conceptual understanding. Because different teams will investigate different aspects of tree health, this discussion can help students see how the results of their investigations relate to others. Do the results of their experiment make sense when thinking about other teams' experimental findings?
20) When conducting the discussion and adding to the storyboard, consider the following:
    a. How do these results relate to the previous investigations done in the module (thought investigations and guided investigations)?
    b. What is the quality of the evidence and reasoning for the explanation given?
    c. Are there weaknesses in reasoning that become apparent? (If this happens while presenting, assure students it is fine to reconsider their explanation.)
    d. How do the explanations developed by different teams reconcile with data from other teams' investigations?
21) If time permits, conduct another open-inquiry investigation. This may be something from the original set of interesting research questions or a new idea that arose during the investigation.
22) Often, one investigation will spark ideas for new investigations. If possible, allow time for students to experience the excitement of science by continuing with a new research question and continuing to interact with their mentors.

Answer Key for Student Questions

How would a disease or insect that damages the tree leaves impact its growth?

Ask students to recall that the function of the leaf is photosynthesis, to produce sugars (food) for the plant. If the leaves are damaged or diseased, it will reduce photosynthetic capacity and thus reduce overall plant growth.

How does poor root growth impact the tree?

Poor root growth will reduce roots' ability to uptake water and nutrients, and anchor the plant. As a result, reduced root growth will impact overall tree health and growth.

How can one quantify the aesthetic value of a tree?

Very generally, trees may impact the value of a home or property. There are also studies that support the positive benefits of nature and a beautiful environment. Ask the students how a beautifully landscaped city or school would impact their own well-being.

If you were asked to decide if the school should plant more trees, what information would be helpful in making these decisions?

Factors that go into this decision include the size and shape of the tree, where the tree will be located, the space available for the tree, resistance to diseases or insects in the

region, ease of maintenance and care, and whether an evergreen or deciduous tree is desired. A good list of factors is included in this article: E. Macie, S. Workman, L Morris, H. Campbell. 2016. Tree Planting in Cities (Part 3): Tree Selection & Planting Guidelines. eXtension.org: articles.extension.org/pages/67409/tree-planting-in-cities-part-3:-tree-selection-planting-guidelines

Websites and Resources Listed in this module:

Plant and Tree Health

- Bal, Tara L. 2014. Forest Health Detectives, an Inquiry and Investigation. American Biology Teacher 76: 536-541. DOI: 10.1525/abt.2014.76.8.7
- Ness, E.. Dec. 2015. Getting to the Root of Urban Tree Health. *CSA News*. dl.sciencesocieties.org/story/2015/dec/thu/getting-to-the-root-of-urban-tree-health
- USDA Animal and Plant Health Inspection Service, Hungry Pests website: www.aphis.usda.gov/aphis/resources/pests-diseases/hungry-pests/
- Williams, S.D. and M.J. Boehm. Plants Get Sick Too! Ohio State University Extension, Ohioline fact sheet: ohioline.osu.edu/factsheet/plpath-gen-1
- Williams S.D., M.J. Boehm, J. Chatfield, J. Boggs and E. Draper. Diagnosing Sick Plants, Ohio State University Extension, Ohioline fact sheet: ohioline.osu.edu/factsheet/plpath-gen-2

Measuring Trees

- City of Portland. How to Measure a Tree. Website with instructions on measuring tree circumference for tree diameter measurements: www.portlandoregon.gov/trees/article/424017
- National Tree Benefit Calculator: www.treebenefits.com/calculator/
- Portland Parks and Recreation. 2014. How to Measure Trees. youtu.be/R9eQ9qFrSVs
- Stephen F. Austin State University, Arthur Temple College of Forestry and Agriculture. 2015. How to measure the height of a tree: www.youtube.com/watch?v=cDy5OjfMfZ8

Tree Care

- Macie E., S. Workman, H Campbell. 2016. Urban Tree Planting (Part 1): Site Selection. eXtension.org. articles.extension.org/pages/67466/urban-tree-planting-part-1:-site-selection
- Macie, E. 2016. Tree Planting in Cities (Part 2): Site Preparation. eXtension.org. articles.extension.org/pages/73692/tree-planting-in-cities-part-2:-site-preparation
- Macie E., S. Workman, L Morris, H. Campbell. 2016. Tree Planting in Cities (Part 3): Tree Selection & Planting Guidelines. eXtension.org. articles.extension.org/pages/67409/tree-planting-in-cities-part-3:-tree-selection-planting-guidelines

Additional Web Resources for Doing Research in the Field:

- Biodiversity in Your Backyard, by the Nuffield Foundation. This lesson plan describes a field experiment to measure species diversity on school grounds. It could be easily modified for use in a nearby park. A plant identification key is provided, but it primarily covers common UK species. http://www.nuffieldfoundation.org/practical-biology/biodiversity-your-backyard
- Discover Life, by The Polistes Foundation. Here you can search for specific species, identify sites where a species has been found, and learn to identify an organism from photos based on its location and traits. Some educational resources are also available. http://www.discoverlife.org/
- Encyclopedia of Life. This resource, which was first thought up by the well-known biologist E.O. Wilson, is a searchable knowledge base that aims to include all species living on Earth. Search for a species by its scientific or common name and find photos, a scientific description, and its conservation status. http://www.eol.org/
- Project BudburstSM: Timing is Everything! by the National Ecological Observatory Network, Inc., and the Chicago Botanic Garden. Here you can learn about phenology, the study of the timing of natural events. Project Budburst is an ongoing project, so you can map your own field observations here and find out what other "citizen scientists" have seen. http://budburst.org/
- Tree of Life, by the Tree of Life Project. This is a good resource for identifying relationships among different species based on current science on evolution. This site also includes photos and descriptions of biological families and genera. http://tolweb.org/tree/phylogeny.html
- The C.V. Starr Virtual Herbarium, by the New York Botanical Garden. This site shows plant samples from the NYBG's William and Lynda Steere Herbarium; it currently has about 225,000 images from over 1.3 million specimens. A glossary of botanical terms is included. http://sciweb.nybg.org/science2/VirtualHerbarium.asp
- Field Techniques Used by Missouri Botanical Garden, by R. Liesner. This page lists a set of articles describing the methods professional field botanists use to find and collect plant specimens, then prepare them for storage in an herbarium. http://www.mobot.org/MOBOT/Research/Library/liesner/tpage.htm
- Backyard Tree Identification Guide contains the basics of classifying & IDing different trees with some helpful pictures. https://www.homeadvisor.com/r/backyard-tree-identification-guide/
- iNaturalist is a great app to help identify local flora and fauna simply by sharing images, and fellow naturalists will help confirm or adjust your identifications. https://www.inaturalist.org/
- The Seek by iNaturalist identification app is an excellent resource to help identify plants, animals and fungi. https://www.inaturalist.org/pages/seek_app