



LESSON SUMMARY

To explore the mechanisms by which water is transported throughout the tree.

Activity Information

Grade Level:	Intermediate/Senior
Estimated Duration:	1 to 3 hours
Materials: Activity #1	These will depend on student designs, but at least some kind of tube (e.g., cardboard, plastic drinking straws, etc.) will be required by all; Activity #2 - copies of the experiment sheet (one per student or group), six stem cuttings of the house plant coleus (each about 15 cm long)' scalpel, six small beakers, water, eosin stain or red ink, hand lens, petroleum jelly
Setting:	Indoors
Key Vocabulary:	Xylem, vessels, tracheids, capillary action, transpiration, photosynthesis, phloem

Background Information

An individual tree can be thought of as molecules, cells, and tissues organized into leaves, branches, trunk, and roots. But a tree is more than the sum of these parts - it is a living, functioning organism. Trees, in fact, are among the most widespread, the largest, the longest living, and the most successful of all living things on the planet. This lesson examines how a tree is designed and the functions played by each of its different parts. It explores how they all work together to keep the tree alive and growing. A key to understanding tree design is the fact that the bulk of a mature tree is made up of dead tissue, whose sole function is to provide protection and structural support. Only about one percent of a tree's volume consists of living cells that need constant maintenance. Nourishment for these cells comes from both ends of the tree – from sugars manufactured in the leaves at the top and from water and minerals drawn up by the roots at the bottom.

The roots of a tree have several functions. They anchor the tree in the soil; they absorb and conduct water and mineral salts; and, in some species, the roots may sprout to produce new seedlings. Water and dissolved minerals enter the tree from the soil through fine root hairs, which are only 0.01 mm in diameter and live for just a few days. Most of the root is inactive, but growing tissue at the root tips produces new root hairs that push the roots deeper into the soil. The water and minerals absorbed by the roots pass up the trunk to the branches and leaves. Water is conducted through the tree in tissue composed of **xylem** cells. In deciduous trees, the elongated xylem cells join end to end to form long, open, microscopic pipes called vessels. A single vessel may be several metres long. In coniferous species, water conduction is carried out by needle shaped cells called **tracheids**, which are 3 to 5 mm long and about 0.03 mm wide. Tracheids have small openings or pits at their ends. These openings overlap with those of other tracheids, forming open gateways for water to pass through from one cell to another. The special design of these water conducting cells allows them to carry water to a considerable height against the force of gravity, to supply the needs of the tissues at the top of the tree. The exact process by which water is taken up by plants against the force of gravity is not fully known. The most commonly accepted theory to explain this process is the cohesion-pull theory, which involves principles of osmosis, molecular cohesion, **capillary action**, and transpiration. Essentially, water is drawn up the long, fine cells by capillary action, a term describing the tendency of water to move in fine spaces because of the molecular attraction between the water molecules and the vessel walls. (Capillary action is also responsible for the movement of water up through soil.) In the leaves, water is expelled to the atmosphere by evaporation in the process of **transpiration**. This loss of water creates an osmotic pressure, exerting a pull through the water-conducting tissues that, together with capillary action, allows the plant to raise water up 100 m or more to the top of the highest trees. This is well above the limit of 10 m, the maximum height to which water can be raised against the force of gravity by human-made suction pumps.

Water has two main functions in the tree. The pressure of the columns of water moving through the plant helps to give the tissues strength and rigidity. You can see this clearly in smaller plants that do not have any woody tissue for support. They depend on their water columns to keep their tissues firm and upright; in hot, dry weather, such plants droop and bend over because they are unable to keep enough water moving through their stems. Water must be constantly drawn up by the roots to replace the water lost through transpiration. A large leafy tree may draw up and transpire as much as 900 L of water every day - enough to fill a bathtub four times. The second use for water in the plant is in the process of **photosynthesis**, in which sugars are manufactured in the leaves from water and carbon dioxide using the energy of the sun. The sugars provide energy for active and growing cells. Sugars are transported from the leaves to the rest of the tree through **phloem** cells located in the inner bark.

Teaching Notes

1. Plan for at least two class periods to conduct Activity # 1. The first part of the activity requires one class period to hold the planning, discussion, and brainstorming session (see Activity #1 for ideas). The second part requires at least one more class period to build the model trees.
2. If you plan to conduct the demonstration in Activity #2, please note that parts of the experiment require more time than one class period. You may modify the experiment to fit your schedule.
3. If you have more than one group conducting the experiment in Activity #2, you will have to provide a complete set of the materials for each of the groups.

Advance Preparation

1. Read through the activities. Decide which ones you wish to conduct and obtain the appropriate materials.
2. If you conduct Activity # 1, students will be creating a list of materials to be obtained for their designs; remind students that materials should be relatively inexpensive and readily available.
3. If you wish to have students conduct the experiment in Activity #2, make copies of the experiment sheet (one per student or group).

ACTIVITY #1

Begin this activity by asking students to estimate the height of the tallest trees they have seen. Then ask: What role(s) does water play in plants? If trees are the tallest living things on earth, how do they manage to conduct water from the ground to this great height, against the force of gravity and without the benefit of any contracting, muscular tissues such as animals use to circulate body fluids? Point out that the limit of a human-made suction pump is 10 m and that trees can grow 10 times this height!

Have the students use their own imaginations and understanding of how trees absorb and transport water to design model trees showing the water transportation system. Hold a brainstorming session to help generate ideas. Students should keep track of the materials that they will require for building their models and plan ways for obtaining them. Many students may attempt to design some kind of pumping mechanism. However, if appropriate, remind students that plants are not outfitted with technological gadgetry; pumps that raise water against the force of gravity are physical processes different from those at work in transpiration. Students should realize that their models must provide transpiration mechanisms; otherwise, at a certain point, the model plant may become saturated with water and might, due to pressure of pumping, explode. (Be on the lookout for potentially messy situations!)

It doesn't matter if the models in no way simulate what actually occurs in plants. "Success" should be measured by the design/production of a reasonable model that accounts for the following processes:

- water up-take by roots from the soil,
- water transport from the roots through the main stem/trunk,
- water transport through branches/petioles to leaves.

During the brainstorming session, you might also provide one or both of the following simple demonstrations to give students an understanding of capillary action.

- Demonstrate the ability of water to travel in narrow spaces by capillary action. Tightly sandwich two glass slides together and briefly touch one corner to the surface of some coloured water. Allow students to observe what happens to the water trapped between the slides. Have them note particularly the appearance of the upper edge of the film of water as it moves between the slides.
- Demonstrate (or invite students to design and demonstrate) that capillary action allows water to move higher through narrow openings than through wider openings. Place several tubes of <different widths (e.g., a piece of glass tubing and a melting point tube) in the dish of coloured water and observe the distance the water travels in each tube. Ask students to account for the difference in height climbed by the water and encourage them to make general statements about how this might apply to trees.

Once students complete their models, ask them to evaluate and decide which are the most successful models in the class. This evaluation process may be the best time to discuss what scientists think is the actual mechanism of water transport in plants. (Some students may even feel inspired to redesign their models to take this added information into account.) This is also a good time to stress the role (and limitations) of theory in science.

Water Transport Through Plant Stems

Activity Sheet

This experiment is reprinted, with permission, from Andrews, William. A. *Biological Science: An Introductory Study*. Toronto: Prentice-Hall, 1980.

Purpose

To observe the movement of water in coleus plants.

Materials

Six stem cuttings of coleus (each about 15 cm long), scalpel, six small beakers, water, eosin stain or red ink, hand lens, petroleum jelly

Method

1. Put the same amount of water into each beaker (several cm), remove some of the lower branches from the coleus stems, and insert one coleus cutting into each beaker. At an angle, cut off 2 cm from the lower end of each cutting while the end is under water. Do not remove the cuttings from the water. (This step removes from the stem any air bubbles that may interfere with the activity.)
2. Coat the surfaces of all the leaves of one cutting with petroleum jelly. Number the untreated cuttings from no. 1 to no. 5 and the one with the petroleum jelly no. 6.
3. Add the same amount of eosin or red ink to each beaker so the water becomes deeply coloured.
4. Put cutting no. 1 in a dark drawer or cupboard and cutting nos. 2 to 6 under a bright light. Leave cutting nos. 1, 5, and 6 for 24 h.
5. After 15 min, examine the stem and leaves of cutting no. 2. Make cross-sections at regular intervals up the stem. Examine them with a hand lens. Record the distance (if any) the stain has travelled. Make a cross-section of one of the lower leaf petioles (the stalk connecting the leaf to the stem) to see if any stain is present.
6. Thirty minutes after adding the stain to the beaker, examine cutting no. 3 in the same manner as in step 5 above.
7. Repeat step 5 after 45 min with cutting.
8. The next day, examine cuttings nos. 1, 5, and 6 as in step 5. Design a table to record all your observations.

Note: Coleus are common annual plants found in most garden centres.

Questions/Follow-up

- Describe any differences among cuttings nos. 2, 3, and 4 on the first day.
- Why were five of the cuttings put in bright light for this activity?
- Did cutting no. 5 absorb more dye after 24 h than cutting no.4 had after 45 min? Account for your observations.
- What effect did petroleum jelly have on the uptake of water? Why would this be so?