Section 2.2 Plant Organ Systems (Student textbook page 70)

In this section, students learn how the root and shoot organ systems which sustain life in plants function.

Common Misconceptions

- Plants are simple organisms with no true tissues, organs, or organ systems. Students require some time of study on plants to appreciate their level of complexity and how it compares to animal organization and complexity. When feasible and accurate, make comparisons to animal internal structure and organization to help students gain understanding. A great point of entry is plant hormones, why plants need them, which cells specialize in making them, how are they transported throughout the plant, etc. A second concept of note is how deciduous trees control the production and termination of photosynthetic leaves in spring and fall, respectively.
- The word sap refers to phloem solution. It actually is used to refer to both phloem and xylem transport solutions. In this text, it has been used for both solutions to prevent propagation of misconceptions, but may need attention drawn to the point, especially for English language learners.
- Students typically associate the word sap with a sweet solution, and then it follows they will think that means phloem occurs at certain times of the year. Xylem also transports sugars (in the spring in the upwards direction).

Background Knowledge

One of the most important terminology notes to observe in regard to plant sap and maple syrup sap collection is that sap is used to refer to solutions found in xylem and phloem tissues. If students have heard the word before, they associate it with sugar solutions, and thus with phloem, which is responsible for most of the sugar transport in plants. In vascular plants growing in seasonal environments, such as *Acer saccarum* (Sugar Maple), xylem is the transport medium for a sugar sap as it moves from the root stores to the shoots and leaves that need the sap to begin growth. This movement is dependent upon the pattern of consecutive days that are warmer than the nights and is forced/suctioned/pressured up the trunk by expanding carbon dioxide gas (in the warmer daytime temperature) produced by growing (respiring) cells above ground.

When it comes to tapping trees to extract xylem sap for maple sugar production, when producers follow tapping guidelines and only use trees that are healthy and are of correct age and size, the tree remains healthy with no permanent damage. Tapping typically removes 10 percent or less of the tree's sugar, an amount proven to be too small to harm a healthy tree.

When students are comparing and studying the structure and function of plant tissues, such as phloem and xylem, they are essentially performing a type of botanical study called plant morphology. Plant morphology "represents a study of the development, form, and structure of plants, and, by implication, an attempt to interpret these on the basis of similarity of plan and origin." There are four major areas of investigation in plant morphology, and each overlaps with another field of the biological sciences (species comparison, vegetative and reproductive structure systematics, differential scale analysis, and patterns of development).

Students are not as familiar with plant organization as they are with vertebrate structural organization. It helps to explain the levels of plant organization and correlate/compare them to animal organization:

Specific Expectations

- **B2.1** use appropriate terminology related to cells, tissues, organs, and systems of living things, including, but not limited to: *absorption, anaphase, capillaries, concentration, differentiation, diffusion, meristematic, mesophyll, phloem, prophase, red blood cells, regeneration, stomate,* and *xylem*
- **B3.6** investigate, through a laboratory or computer-simulated dissection of a plant, worm, fish, or frog, the interrelationships between organ systems of a plant or an animal
- **B3.3** explain the links between specialized cells, tissues, organs, and systems in plants and animals

Organism	Plant - Sugar Maple Tree *(Acer saccarum)*	Animal - Human *(homo sapiens)*
Organ systems (group of organs that work together to carry out a particular task)	root and shoot	circulatory, digestive, endocrine, integumentary, lymphatic, muscular, nervous, reproductive, respiratory, skeletal, urinary
Organs (group of tissues that perform a specific function or group of functions)	reproductive flower (modified leaf), leaf, stem, root, seeds, fruits	heart, liver, lung, brain
Tissues (a collection of cells that are similar in structure and function)	meristematic (apical, lateral, intercalary), simple (parenchyma, sclerenchyma, collenchyma), complex (phloem, xylem, periderm)	epithelial, connective, muscle, nervous

Various theories have been developed to account for the movement of water through the plant. The theory most consistent with the data is the cohesion-tension theory. Since root pressure does not exist in all plants and is not strong enough to push water to the tops of tall plants, the cohesion-tension theory is the best explanation for this movement. The water columns in xylem tubes are under high tension as water moves up the plant. This tension causes the potential of the water to become more negative at the tops of trees compared with the bases of trees.

The hydroponic technique has been around for over 100 years, but came to prominence in 1936 when Dr. W.F. Gericke (University of California) grew a tomato vine that was approximately 7.5 m tall using hydroponics. He coined the word, which comes from two Greek words meaning "water working." From there, the field grew to what it is today, a great agricultural application.

Literacy Support

Using the Text

- Have students form the framework for new learning about plants by asking them to consider the organs and organ systems involved in transportation in vertebrates.

Before Reading

- Prompt students to look for opportunities in this section where two concepts or structures can be compared (root and shoot, xylem and phloem, soil and soil-less cultivation). Have students review how to construct a Venn diagram and use it to compare several concepts. You may wish to have students use **BLM G-47 Venn Diagram** for this activity.
- Have students prepare a table for about 10 words (perhaps as an informal contest) that have a common and scientific meaning.

During Reading

- Use the Study Toolkit prompt on page 71 to compare and contrast concepts on that page.
- Have students reflect on and discuss the Sense of Place on page 72. Venus flytrap and pitcher plants do not make their own food due to living in nutrient-poor environments. Ask students if they have any prior knowledge of these plants. Where do they live? Are they native to Canada? Do they both have the same nutrient challenges, or are their deficiencies different in nature? Do they use the same coping mechanism for obtaining nutrients?

- Have students reflect on and discuss the Sense of Value on page 75. The maple industry (syrup and other products) is worth an estimated $15 million a year. Is this a lot? How does it compare to other industries? To other trees? Is there any other tree that has a unique use such as sap (non-traditional use other than paper, pulp, wood, structural). Cork may be an answer students give; ask them to find out what tree(s) provide cork for bottling or other applications.
- Have students attempt to label these diagrams on their own, as well as either drawing their own labelled diagrams or labelling other similar diagrams. (Figures 2.20, 2.23, 2.24, 2.25)
- Have students create a list of the benefits and risks of girdling a tree (for humans and for the tree).
- Have students add new words to a word wall or word page in their notes as they read; consider having students represent definitions pictorially instead of with words.
- Continue to have students monitor and record growth changes in their bean plants.
- Have students make connections between reading and experience.

After Reading

- Have students reflect on the following Big Idea: *Plants and animals, including humans, are made of specialized cells, tissues, and organs that are organized into systems.* Perform a didactic example review to ask students to recall specific examples of plant tissues, organs and organ systems.
- Perform a formative assessment of learning by having students answer the Learning Check and Section Review questions.
- Perform a simple dissection of a plant by bisecting a plant at the ground surface, cutting it into the root system and shoot system. Give the different parts to different groups. Ask them to consider the cells, tissues, and organs present in their system, the main function of their system, what their system cannot do without the other system, and what types and arrangements of tissues are present (dermal, ground and vascular tissues).
- Have students connect new learning to previous learning and what they know by asking them, "How does this new information add to or alter what you already knew about the topic?"
- Perform Investigations 2-A and 2-B to investigate the process and factors that affect transpiration through xylem tissue.

Using the Images

- ELL The term *root hairs* is easier for ELLs to learn as the structure itself looks like the term given to it (Figure 2.22). Ask students to think of other instances where the name given to the structure matches its appearance (leaf veins, guard cells).
- Reflecting on Figure 2.19 is a good opportunity to ask students what First Nations people might use trees for, and how that compares with how non-First Nations people use trees. Consider also the spiritual side of using trees. Ask students if they can recall any fables, rhymes, songs, or stories that use trees as metaphors for a lesson.
- Have students break down the word *hydroponic* to figure out its meaning. If stuck, refer students to Figure 2.21, which only hints at the soil-less growing conditions in the image. Ask students to draw where the pipes go, and consider what other apparatus is necessary for soil-less cultivation.
- Remind students about the process of osmosis; that water has its own concentration gradient whereby it follows the higher concentration of solute while learning new material about root absorption in Figure 2.23. Here, there are more solutes in the plant cells than in the surrounding soil (the plant is hypertonic to the soil) and thus water has a higher concentration outside the plant cells than inside, and moves into the cells, down its concentration gradient. Have students look back at their notes and Figure 1.22 to see the connection between osmosis and root uptake.
- Help students learn the complex and numerous concepts in Figures 2.24 and 2.25 by presenting them with an unlabelled diagram and have them describe what they see in their own words. Encourage them to use single words, or additional pictures if sentences are too challenging. Both figures are useful for students to orient themselves as to what they are observing, and the relative scales and proportions. This is especially important when trying to conceptualize cell and tissue processes, like transpiration. Make sure students are clear about the words "adhesion" and "cohesion" (they can draw analogies to show understanding), their similarities and different meanings. Substitute the word "sugar," or a picture of table sugar, for sucrose.

Assessment FOR Learning		
Tool	**Evidence of Student Understanding**	**Supporting Learners**
Activity 2-3 The Flow of Phloem, page 71	Students should show understanding that girdling a tree means cutting off the phloem transport flow of sugar from the leaves to the roots They should understand that girdling has: the short-term effect of creating a bulge above the girdle and sweeter fruit; the long term effects of killing the tree due to death of non-photosynthetic root cells no longer able to carry out their water absorption function.	Have students review Figure 2.3 as well as pages 59-65. Ask students to draw a simple diagram of a tree showing all locations of xylem and phloem. (Answer: in every organ) Ask them to place arrows on the vascular tissues to show direction of flow. Have the students orally explain to you what is found in xylem sap and phloem sap. Lastly, ask them what the roles are of mesophyll cells and root cells. Ask students what the purpose is of bark, and what happens when bark is removed from a tree. Show students additional cross section images of bark and cambium to indicate where the vascular bundles are located in trees. Ask students to pay particular attention to the radial location and relationship of xylem and phloem. Students may find that **BLM 2-6 The Flow of Phloem** provides the scaffolding they need to complete the activity.
Learning Check, page 72	Students understand that there are other ways for plants to obtain nutrients and water other than soil. Students should draw two organ systems and understand that the basic criteria for this delineation is the ground (root system below, shoot system above). Students should be able to make a connection between plant necessities and increased growth due to (unlimited) availability.	Remind students what plants need (sunlight, carbon dioxide, water, and minerals) and that the first two come from the atmosphere, the second two come from the ground, so plants need a way to move things around internally to ensure all cells have what they need to perform photosynthesis (make sugar) and cellular respiration (burn sugar for energy). Lastly, that plants grow well when these items are available in good quantities.
Section 2.2 Review, page 76	Students answer question 1 and communicate that they know that: xylem and phloem are types of plant tissue that pass through all organs and organ systems; that xylem's structure is comprised of dead tubular cells, which perform passive transport, and it's function is to transport xylem sap, which is mostly water and minerals, from the root system to the shoot system; xylem sap moves by a pressure push from below and a transpiration pull from above; phloem's structure is comprised of living tubular cells (sieve cells) and it's function is to transport photosynthetically produced sugar in phloem sap from the leaves to other organs. There are two organ systems in plants: roots and shoots. In answering questions 2 and 3, students demonstrate that they can think critically and demonstrate understanding about transpiration and the connection to open stoma. Students design a short test to demonstrate that stoma are located on the bottom of a leaf, and that they transpire.	For questions 2 and 3, students will require more visual conceptualization–more hands-on activities, video clips, animations. For example, refer to the Instructional Strategy for modelling stoma opening with balloons. Hint that something should be tested on the tops and bottoms of leaves, that water is evaporating. Refer students to Science Skills Toolkit 2 on pages 532 to 535 of the student textbook. Students may find that **BLM G-5 Scientific Inquiry Organizer** helps them get started.

Instructional Strategies

- ELL For struggling readers and ELLs, present content in pictorial form as much as possible. Use the images in the text as lesson substance, keep writing to a minimum, have students label diagrams, and then have students form groups to perform peer formative assessment.
- Start with a hook that engages the senses—maple syrup, sugar, fudge, or ice cream (check for allergies first). Have students sample it, or boil maple syrup until it crystallizes and share with students. Accompany with a video clip on maple tree tapping.
- Alternatively, have samples of sucrose and starch available for tasting (check for allergies first). Students can begin with an understanding of solubility as they watch you attempt to dissolve the same amount of amorphous starch and crystalline sucrose into the same amount and temperature of water (sucrose will dissolve, starch will dissolve minimally). Display images of these molecules to show the different structures and sizes, but also the similarities (sucrose is a disaccharide of glucose and fructose).
- Attempt to make as many connections to applications and examples of plant transport as possible. Approach this as an STSE opportunity. Ignite student ability by posing questions about phenomenon they have experienced. For example, why are some plants unable to grow in salty soils at the seashore or along roads where de-icing salts are commonly used? Does this have anything to do with the concept of water potential? How does this affect ecosystems and biodiversity? What can we do to combat this? Ask further as to what technologies we might be able to devise as a solution to existing problems using the unique design and functionality of stoma? How tall are the tallest living trees? What are the advantages to growing to these heights? What are the physiological problems faced by the tallest trees?
- Students may wish to investigate the different ways in which water enters the root hairs, including transcellular, apoplastic, and symplastic.
- Students may wish to explore the cohesion-tension theory in greater detail as it accounts for the movement of water through the plant.
- A potometer is a device that measures water movement through the plant. To construct a potometer, a plant shoot is cut underwater and inserted into a water-filled tube, to which a calibrated pipette is attached. A variety of demonstrations can be performed, including varying environmental conditions to observe the effects on transpiration, including wind and humidity.
- Model stomata by taping a straw into a balloon's neck. Repeat with a second balloon. Half-inflate each balloon, then plug the straws with modelling clay. Wrap each balloon with tape so they look like candy canes, and attach the bottoms together. Fully inflate both balloons. The ends remain stuck together but the outside of the balloons expand so that an opening is created in the middle, representing the open state.
- Have students carry out Plan Your Own Investigation 2-A Transpiration in Different Plant Types. See page TR-2-60 of this Teacher's Resource for notes on this activity.
- Have students prepare their own stomata slide from a leaf. First coat an area of the leaf with clear nail polish. When it is dry, us clear tape to peel the patch off the leaf and press it only a slide. Use a microscope to find and sketch the stomata.

Activity 2-3 The Flow of Phloem (Student textbook page 71)

Pedagogical Purpose

Students are given an opportunity to learn about a historical experiment, to infer the outcome of the experiment, and to think about the connection between tissue location, function, and plant survival. Students may work in groups or individually.

Planning	
Materials	**BLM 2-6 The Flow of Phloem** (optional)
Time	20 min

Background

Marcello Malpighi (pronounced MAL-pi-(short i)-gee) was an Italian physician and biologist. Malpighi is considered by some to be the founder of microscopic anatomy and the first histologist. Many microscopic anatomical structures are named after him, including a skin layer (Malpighi layer) and two different Malpighian corpuscles in the kidneys and the spleen, as well as the Malpighian tubules in the excretory system of insects. He also studied embryonic development, was one of the rare biologists who performed analytical study on plants, and published his work in *Anatomia Plantarum* in 1671, and was also published in English by The Royal Society. A family of tropical and subtropical flowering plants was named in his honour by Linnaeus (Malpipighiceae). This is an opportunity to layer on a discussion about the nature of science and scientific experimentation with students. You may wish to refer students to or open a class dialogue about the skills and study of science discussed in Science Skills Toolkit 1.

A point of confusion may arise for the student regarding tree health. The account of Malpighi's experiment notes that, although it appeared at first that the tree was not damaged, indeed it died a few weeks later. However, in question 3, background information is given that indicates that girdling is a sustainable practice fruit farmers utilize to produce sweeter fruit. This appears contradictory, and students may pick up on this contradiction. In the case of Malpighi's tree, there are many factors that may not have been considered in determining the overall health of the girdled tree. After decades of successful girdling, the following have become accepted as the primary conditions that need to be met in order for a tree to survive: no drought, extra or adequate nitrogen treatment, proper girdling technique, pest control to prevent infection while the wound is healing.

In order for girdling not to affect the overall health of the tree, farmers need to practise sustainable measures.

Activity Notes and Troubleshooting

- Some students may benefit from working from the visual information in the activity, while others can use the visual information as experiment support to the text.
- Procedure 2 asks students to sketch a cross section of the tree stem in Malpighi's test. Make sure students understand that they are to sketch Malpighi's tree, and not replicate Figure 2.10.
- Show students images of trees that have been partially cut down (i.e., just stripped/peeled) by beavers. Ask them how this is the same or different from Malpighi's experiment. This will provide evidence as to whether the students understand what Malpighi did in this experiment.
- Some students may need assistance with the concept of girdling; that is, connecting the text information to the procedure. It may help to perform a girdle in class. For example, use a potato peeler and any kind of fruit, and peel a middle layer of the skin off, without going too deep. Alternatively, use the stalk of broccoli with the florets still on and girdle the stem.

Additional Support

- DI Ask students what tools Malpighi would have had at his disposal to perform the bark peeling, engaging bodily-kinesthetic learners.
- Ask students to think about how many trees you might try the same experiment on in order to confirm Malpighi's experiments. What is a good sample size?
- To promote creative thinking, ask students if there is any way to design an experiment that tests what happens when xylem sap flow is prevented.
- To promote creative thinking, ask students if they can think of any other way to increase the sweetness of fruit.
- Students may find that **BLM 2-6 The Flow of Phloem** provides the scaffolding they need to complete the activity.
- Use **BLM A-40 Scientific Drawing Rubric** to assess students' diagrams.

Answers

1. Malpighi's results indicated that something near the surface of the bark was removed; likely a transport tissue that prevented the transport of an essential nutrient. From my sketch, I infer that the phloem is close enough to the surface of the bark to have been the transport tissue removed. Also, I know that phloem conducts sugars from above to below, and the wounded vessels in the swollen area above the wound were oozing sweet sap–further concluding it was only the phloem tissue that was harmed.
2. There may have been a swelling below the wound, instead of above. Also, the leaves and non-woody leaf stems above the girdle would have wilted without sufficient water to support the cells. Photosynthesis requires water; without this water from the roots, the process would slow to a halt, and tree life would be severely threatened.
3. **a.** The sugar does not have a direct route to the root system, where it is in demand. The excess sugars would need to be stored; fruits provide a storage vessel for sugar.

   b. In Malpighi's experiment, the tree eventually died. It appears girdling has some short-term benefits for the farmer and consumer, but does long-term harm to the tree. If this practice is used consistently in agriculture, it must be because there is a sustainable way to do it without adversely harming the tree; a way that Malpighi did not employ in his experiment.

Learning Check Answers (Student textbook page 72)

1. Plants can grow in certain nutrient solutions instead of soil.
2. Diagrams should indicate the root system (all beneath the surface of the ground) and the shoot system (stem, leaves, and flowers).
3. Nutrient-rich soils will promote large root systems in these plants.
4. Too much water on a lawn will reduce the amount of oxygen that is available for cellular respiration by root cells.

Section 2.2 Review Answers (Student textbook page 76)

Please also see **BLM 2-8 Section 2.2 Review (Alternative Review).**

1. Both xylem and phloem are components of the plant's vascular bundles. Xylem tissue transports water and nutrients from the root system to the rest of the plant. The phloem transports sugars that are produced from photosynthesis in the leaves to other parts of the plant. Xylem tissue does not use any of the plant's energy stores, but phloem tissue does.
2. The open pore, represented in diagram A, will exert a stronger pull on water from the roots. The open pore allows water vapour to escape into the atmosphere and makes room for more water.
3. Example: I would cover the bottom side of the leaves with something to block transpiration (such as petroleum jelly) and measure the rate of transpiration. I would then repeat this with the upper side of the leaf and compare the rates of transpiration.
4. A tulip will transpire more in a dry environment. A humid environment has a higher concentration of water vapour in the air. When stomata open, there will be less of a tendency for the water vapour to evaporate into an atmosphere of high humidity.
5. When the stem is bent to broken, it interrupts the flow of water and nutrients to the plant above that point on the stem. This will eventually cause that section of the plant to die.
6. Maple sap is collected in the spring because the sap contains the highest amounts of sucrose at that time of year. In spring, starch that was stored in the root system is broken down into sucrose and transported into the shoot system, through the xylem, to be used in other parts of the plant.
7. Flowcharts should indicate that, in spring, transport of food (sugar) is primarily up the tree, from the roots to the shoot system for growth and leaf production. In summer and fall, transport of food (sugar) is from the leaves to other parts of the plant, including the roots where it can be stored as starch.
8. The rate of sap retrieved would be greatest during the night. At that time, photosynthesis cannot be carried out and glucose is not synthesized in the leaves. Therefore, sucrose must be transported from the root system.

Plan Your Own Investigation 2-A Transpiration in Different Plant Types (Student textbook page 77)

Pedagogical Purpose

Transpiration study can provide some insight into the physiology, anatomy, and cellular processes occurring in a plant. Comparison of the process of transpiration through stoma in different plants allows for deeper analysis of the process itself; its rate, efficiency, and degree of variance among representative plants. Students are introduced to scientific investigation proficiencies of planning, performing, recording, and developing their use of those skills for future continued success in Plan Your Own Investigations.

Planning		
Materials	A variety of small potted plants Clear plastic bags (large) Elastic bands (optional) A week before, have students bring in small plants.	Measuring spoons or cups Modelling compound (optional) Potometer (optional)
Time	60 min	
Safety	Remind students never to eat or drink in the laboratory. Ensure students wash their hands after the investigation.	

Background

Before a comparison analysis on the different rates of transpiration in plant species can be performed, an understanding of the process of transpiration is essential.

The long-distance transport of water is controlled by an osmotic pull called water potential. Recall that water will flow from an area of high concentration to an area of low concentration. Water potential is also affected by pressure, gravity, and solute concentration.

Most of the water absorbed by roots is not used for photosynthesis, but the fact is that every cell requires an aqueous solution for its reactions. Therefore, the transpiration pull performs the action of pulling water up from the roots where it can be laterally transported and distributed to every cell (after the hydrostatic pressure has pushed it up a small distance). When excess pressure builds up in the leaves at night, and evaporation due to transpiration is at its lowest rate, the leaves perform the process of guttation (through openings called hydrathodes) to prevent the downward, counter-productive flow of water.

When comparing transpiration rates of different plant species, it is critical that data is comparable. To meet this criteria, the surface area of the leaves should be measured so the rate of transpiration equation can be employed to draw conclusions (see Activity Notes for more information).

To guide the extension investigations, keep in mind that plants transpire more when they are exposed to sunlight and excess wind, and when the moisture content of the air (humidity) is less than the concentration of water inside the leaves.

For students who are interested or show aptitude, target the mathematical analysis of the recording and graph results to demonstrate differences visually.

Activity Notes and Troubleshooting

- Graduated cylinders may be used to measure water, or balances can be used to assess weight rather than volume.
- A potometer could be used rather than measuring water (transpiration) volume.
- You may wish to view each part of group planning separately, to ensure accuracy and success, with the following checks: hypothesis; step-by-step outline of procedure; data recording sheet.
- Results can be viewed after 30 min but, ideally, the test should run for 24 h in order to see a larger degree of difference between the plant species.
- Have students calculate the total leaf surface area prior to the test, so that they can later compare ratios.
- To increase accuracy of the design and the results, total lower leaf surface area may be calculated and used to explain why one plant species transpires more than another.
- Set aside an area of the classroom for the plants, preferably where all the plants can receive equal light.
- Guide the students to thinking about what variable they are testing (transpiration rates), what variable is independent (different plant varieties), and how to control all non-tested variables including light, soil, water, nutrients, etc.
- Students may wish to consider plant size in their experiments. To keep things simple, suggest plants of similar size and total leaf surface area. To increase complexity of outcome analysis, plants of different sizes and total leaf surface may be used.
- To measure the amount of water transpired into a bag, weigh the bag before and after the timed test. For water, essentially 1 g equals 1 mL. With this method, make sure students seal the bags tightly around the base of the plant and that all leaves are inside the plastic bag.
- The hardest part of the design will be how to collect and measure the amount of water accumulation inside the plastic bags. This will be the greatest source of experimental error, and the most difficult for students to accomplish. Guide students to make mid-experiment revisions to the collection technique so that they can feel successful in observing and addressing experimental design challenges (just as scientists also continually perfect technique).
- You may wish to have students create a slide presentation as a lab summary, showing their procedure, set-up, table of results, and summary of conclusions.
- In order to accurately communicate findings and compare results, transpiration rates are measured in $\frac{\text{mL}}{\text{m}^2}$, which does require leaf surface area calculation:

  $$\text{Rate of Transpiration} = \frac{\text{total water loss (mL)}}{\text{surface area (m}^2\text{)/time}}$$

- Use **BLM A-42 Design an Investigation Rubric** to assess students' investigations and **BLM A-35 Measuring and Reporting Rubric** to assess their observations.

Additional Support

- DI Consider this investigation as two pieces: a planning piece that involves skills of hypothesizing and procedural writing, which is more linguistic and logical in nature, using interpersonal skills; a performing and recording piece, which is more bodily-kinesthetic and logical-mathematical in nature, with more intrapersonal work.
- DI For logical-mathematical learners, target the mathematical analysis of the recording and graph results to demonstrate differences visually.
- Some students may benefit from using a data sheet to help with the planning process.
- Some students may benefit from drawing a series of pictures to demonstrate their design procedure, to help them articulate their design.
- This investigation offers a great opportunity for students to extend their skills of inquiry and design and consider how another factor (e.g., light, humidity, temperature, wind, soil moisture, internal concentration of CO_2) affects transpiration of the same type of plant. Since the plants are already housed in the classroom, a natural extension of testing would flow from the end of this investigation and question 7.

Answers

1. Example:

Transpired water (mL)				
	Plant 1	Plant 2	Plant 3	Plant 4
Transpiration rate (mL/m^2)				

2. Encourage participation in group discussions.

3. Example: I can infer that the total leaf surface area is a factor in the rate of transpiration; the more surface area, the more transpiration. It would also appear that broad-leaf plants transpire more than thin-leaf plants.

4. Students should evaluate the match between data and hypothesis as well as sources of error.

5. Examples:
- Use a potometer instead of a plastic bag.
- Change the length of time of the running experiment.
- Use different plant varieties that have the same calculated total leaf surface area in order to give more credibility to the results as they represent transpiration rates in different plants.
- Accurately calculate total leaf surface area.
- Improve method of water collection and measurement in plastic bag.

6. The closer the ratio of leaf to plant, the more transpiration there was.

7. Example: Test a single plant in a variety of conditions.

Inquiry Investigation 2-B Moving Nutrients Though the Stem

(Student textbook page 78)

Pedagogical Purpose

This is a great opportunity to develop student understanding of the mechanics and process of designing and performing a double variable investigation. In this test, students will study the effects of a bag covering the transpiring leaves of celery stalks, representing an increase in humidity (and to a lesser extent, temperature), as well as the transpiration rate of a stalk with no leaves. A control stalk will also be set up to help students understand the function and necessity of a control. Results are easily obtained so that students can also practise interpretation, communication, and conclusion-drawing skills of scientific investigation.

Planning		
Materials	Three 100 mL beakers Medicine dropper 3 celery stalks with leaves Red food colouring Tap water	Small plastic bag Elastic Single-edged razor blade or sharp knife Cutting board or other cutting surface **BLM 2-7 Moving Nutrients Through the Stem** (optional)
Time	30 min over two days	
Safety	Remind students never to eat or drink in the laboratory. Handle sharp objects with care. Never cut an object held in your hand, and cut with the blade moving away from you.	

Background

Discuss with students the meaning of *stalk*, which has not appeared in their learning to this point. Ask them to which organ or part of the plant they think it belongs. Ask them to observe the shape and general anatomy of a stalk, and compare it to other parts of a generic plant. They should see that stems are round, or circular, yet a stalk is a semi-circle, or crescent shaped. It is not a stem; in fact, it is the part of the leaf stem, called the petiole. Petioles are small stalks that attach the leaf blade to the actual stem. In terms of internal anatomy and vascular bundle structure, petioles are much like stems in organization.

Activity Notes and Troubleshooting

- The celery must be in good condition for this investigation to work.
- The best stalk length is 10–20 cm, not including leaves.
- Depending on classroom ambient conditions (i.e., quantity and intensity of light, air flow, etc.) the test may come to completion long before students arrive the next day to check their stalks. You may need to check the stalks on the same day to ensure there is a noticeable difference in the three stalks.
- This is an easy and quick investigation. If there are enough materials, you may consider having students work individually for maximum hands-on and responsibility.
- You may wish to do all of the cutting. Alternatively, have a specific cutting station near your work area.
- Blue food colouring will work equally well.
- Make sure each student/group has labelled their beakers.
- Make sure that the three beakers are exposed to identical elements, including light and temperature. Keep them side-by-side.

- Use **BLM A-40 Scientific Drawing Rubric** to assess students' diagrams.
- The investigation is open as to the quantity of water. Have students think about this critically, but 4–8 cm is enough; ensure enough food colouring has been added to make the solution as dark as possible.

Additional Support

- Allow for creativity and alternative tests. Students may propose a variation, extension, or improvement to the procedure before they begin.
- After the investigation, have some or all students model a cross-section of a celery stalk, showing the location and arrangement of vascular bundles.
- Some students may benefit from a demonstration of the procedure to model.
- Allow visual learners to view a thin cross section under a microscope or with a magnifying glass, in order to view the vascular tissue up close, after the food colouring has been absorbed.
- To preserve textbooks and scaffold the process, provide students with **BLM 2-7 Moving Nutrients Through the Stem.**

Answers

1. Encourage students to critically assess the link between their data and hypothesis.
2. Examples: wind or air flow; ambient temperature; blockage of stomata; light; total leaf surface area; relative humidity; root health; soil moisture level
3. wind, blockage of stomata, light intensity, and relative humidity
4. Diagrams should show that the dyed water moved farthest up the stem in the normal celery, and least in the stalk without leaves. Labels should include vascular bundles, xylem, phloem, petiole/stalk, leaves.
5. The amount of leaves. Without leaves, plants do not transpire and pull water up efficiently. The stalk with no leaves had little or less movement of coloured water—the coloured water did not make it to the top. Wrapping a bag around the stalk is a factor; essentially raising the humidity level around the stoma. When the humidity reaches close to or higher than the internal moisture level of the leaves, transpiration slows or halts. The evidence is that this stalk did not have the same water movement rate as the control stalk.
6. Carnations work very well. Ensure stems are cut just before immersing them in coloured water. Consider mixing new colours with the food colouring.