Plant Physiology – The Plumbing of Plants

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Unit Overview

Target Audience:	Est. Time:	Content Area(s): Science, Environmental Science, Mathematics, and Engineering
Elementary School (4-6)	Three 55-minute class periods	

Abstract:

In this unit, students will investigate how plants pull water from the soil to support photosynthesis. The importance of understanding plant biology and physiology is highlighted through three lesson plans focused on inquiry-based and project-based learning approaches. In Lesson 1, students identify plant tissues and explore the significance of plant water transport efficiency through sample and group calculations of flow rates from different species. They also engage in project-based learning by designing a leaf model to understand the importance of each layer of a leaf and discuss variation across species. Lesson 2 delves into plant physiological responses, particularly water transport mechanisms, through experiments on osmosis with potato cores and discussions on stomatal responses to environmental stimuli, such as drought. The examples of drought will then be related to water management strategies in an agricultural field. Students then analyze the impact of stomatal size variation on water loss and discuss the mechanics behind stomatal opening, and then calculate canopy transpiration. Finally, Lesson 3 introduces students to designing a plant hydraulic network, fostering critical thinking in evaluating and improving designs for efficient water transport. Through these hands-on activities and experiments, students scale their findings to ecosystem-level understanding and thinking. These lessons underscore the interdisciplinary nature of plant biology, mathematics, and engineering design, fostering deeper comprehension and appreciation of plant systems. This interdisciplinary lesson integrates grades 4-6 Indiana Science Standards and AFNR standards through inquiry and project-based learning approaches.

Unit Goals/Objectives:

1. Be able to identify the anatomy of a plant based on variation in species morphology.
2. Be able to identify how a plant's morphology and physiology are related in their photosynthetic response.
3. Be able to design a model of the anatomy of a leaf.
4. Be able to describe how plants take water from the soil.
5. Be able to explain how plants cope with drought.
6. Be able to construct a replica efficient model of the plant hydraulic network.

Lesson Summaries:

Lesson 1: ***Plant Anatomy and Model Building***

Students will apply an inquiry-based learning approach in order to identify different plant tissues. There will be formative questions to gauge the students initial understanding of plant systems. The lecture will be accompanied by a presentation that begins with basic human anatomy. This will be done through the beginning lecture and then subsequent flower identification and floral formulas. Students will then calculate (Using the Hagen Poiseuille equation) different flow rates from data given from different species and then discuss how these factors affect plant water transport efficiency. Students will then apply a project-based learning approach and design a model of a leaf with the given supplies; students will then be able to discuss the importance of each cell within the leaf.

Lesson 2: ***Plant Physiological Responses (Water Transport)***

Students will apply a project-based learning approach to how plants take water from the soil through osmosis in an experiment examining the effects of a potato core at varying levels of saltwater concentrations. Students will then apply an

inquiry-based learning approach in order to explain how stomata respond to environmental stimuli. Students will discuss how variation in stomatal size impacts total plant water loss. Students will then be able to discuss why the guard cells surrounding the stomata have to push back against the epidermal cells in order to open when the leaf is at full turgor.

Lesson 3: ***Design and Make a Plant Hydraulic network. (Project building and competition)***

Students will apply a project-based learning approach to design a plant hydraulic system and evaluate the design for the most efficient water transport. Students will then be able to explain why some designs were better or worse than others and reconstruct their designs. Using a syringe to suck water from different soils at varying levels of saturation, students will then discuss the variation in force it took in order to transport the water and then be able to scale results to ecosystem-level thinking.

Lesson Timeline:

Lesson 1 (55-minutes):

- Introduction/Entry ticket: 5 minutes
- Lectures: 10 minutes
    - Begin lecture on the basic anatomy of plants, with the terminology of different organs with formative assessments. Pass around 3-D printed models of anatomical representations from CT scans of a variety of native species in Indiana. While students are examining models and lectures about basic stem and leaf anatomy. Discuss how variation in anatomical structure leads to variation in photosynthetic efficiency (Hagen Poiseuille Equation and stomata density and size).
- Perform flower identification and floral formula, then compress and dry plant material for later storage: 15 minutes.
- Construct a 3-D model of a leaf in teams: 10 minutes.
- Teach how plants take water from the soil: 10 minutes.
- Exit ticket: 5 min

Lesson 2 (55-minutes):

- Introduction/Entry Quiz: 5 minutes
- Review: 5 minutes
- Perform Potato activity at different saltwater concentrations (make a hypothesis of what will happen): 15 minutes.
- Perform stomatal impression from leaves: 10 minutes.
    - From leaves from nearby trees, have students perform stomatal impressions with clear nail polish and look at the stomata under a microscope.
- Discuss findings from potatoes: 10 minutes.
- Discuss that stomata can close to prevent water loss: 5 minutes.
    - Perform stomata bike tire activity to discuss hydro-active force.
- Exit Quiz: 5 minutes

Lesson 3 (55-minutes):

- Introduction: 5 minutes
- Review: 5 minutes
- Teach about design criteria for plant hydraulic system: 5 minutes.
- Design and make a straw-designed hydraulic network: 20 minutes.
- Test the hydraulic network with different soil moisture levels:10 minutes.
- Discuss results: 10 minutes

STEM Integration within the Unit:

- STEM is integrated in lesson one through the connection of science and mathematics in how the radius and length of the xylem affect the rate of water flow within a plant. Further, lesson one also integrates engineering design through the model construction of the anatomy of a leaf. Lesson one relates to AFNR and how flowers turn into fruit for agriculture. STEM is integrated in lesson two through experimentation of water transport with the potato core. Further, lesson two integrates mathematics through mathematical reasoning to calculate stomata density from a whole canopy. Canopy transpiration will be calculated for a maize field to determine different water management strategies. STEM is integrated in lesson three through engineering design and mathematical reasoning skills to design the most efficient plant hydraulic network made of straws.

Lesson 1: Plant Anatomy

Est. Time: 55 minutes

Lesson Learning Goals/Objectives:

1. Identify different parts of the plant.
2. Be able to calculate flow rate and explain differences in flow rate across species.
3. Explain how variation in anatomical structure leads to variation in water transport.
4. Describe the importance of the cellular locations of the anatomy of a leaf to support photosynthesis and diffusion of carbon dioxide into the leaf.

Standards:

5-LS1-1 Support an argument that plants get the materials they need for growth chiefly from air and water.

5-LS2-1 Develop a model to describe the movement of matter among plants, animals, decomposers, and the environment.

PS.02.01.01.a. Identify and summarize systems used to classify plants based on specific characteristics

PS.02.02.02.a. Identify and summarize the components, the types and the functions of plant roots.

PS.02.02.04.a. Research and summarize leaf

	morphology and the functions of leaves PS.02.02.03.c. Evaluate the function of the xylem, phloem and cambium tissues and the impact on plant systems. PS.02.02.05.a. Identify and summarize the components of a flower, the functions of a flower and the functions of flower components. 4-LS1-1 Essential Construct an argument that plants and animals have internal and external structures that function to support survival, growth, behavior, and reproduction. 3.CA.3: Model the concept of multiplication of whole numbers using equal-sized groups, arrays, area models, and equal intervals on a number line. 5.CA.2: Solve real-world problems involving multiplication and division of whole numbers 3.CA.5: Multiply and divide within 100 using strategies such as the relationship between multiplication and division 4.NS.3: Use fraction models to represent two equivalent fractions with attention to how the number and size of the parts differ even though the fractions themselves are the same size 4.CA.5: Solve real-world problems with whole numbers involving multiplicative comparison 4.M.3: Use the four operations to solve real-world problems involving distances, intervals of time, volumes, masses of objects, and money.

Assessments

Pre-Assessment:

- Exit and admit slip.

Formative:

- Asking what the students can tell me what they know about plants.
- Question from slide to identify the parts of a tree.
- Students will have individual whiteboards for calculations of flow rates.
- What will have a greater flow rate?
- Raise your hand questions.

Summative:

- Quiz over plant structure

Concept Prerequisites or Background Knowledge Needed:

- Multiplication and division skills (arithmetic)

Vocabulary:

Xylem, phloem, stomata, cells, stamen, carpel, filament, anther, petals, flora, formula, mesophyll, palisade, epidermis, trichome, vessels, potential, diffusion.

Materials & Technology Needed:

3D models of stems, whiteboards, markers, plexiglass boxes, Styrofoam squares, Styrofoam balls, an organized grid-like material for palisades, cardboard, sticks, and tubing for vessels

Lesson Component	Instructions	Materials
Introduction + Pre-Assessment *Time: 5 min* **Lecture:** *Time: 10 min*	*Pre-Assessment:* - Have students complete entry tickets. *Introduction:* -Discuss the plan and goals for the lesson. *Lecture Topics:* -Pass around 3D models of micro-CT scans of different species around to the class and lecture about the structures they are seeing. Discuss how the large pores they are seeing are actually the water-conducting vessels of plants, moving water from the soil to the leaves. Discuss that the flow rate of water can actually be calculated. Have whiteboards so students can follow along. Discuss how there is wide variation in morphology in the plant kingdom. Bring up leaves as an example and ask the students how many cells they think leaves are. Discuss leaf anatomy and its importance for photosynthesis. Further, Angiosperms are a great example of variation because their flowers are very obvious and unique. Have flowers and pass them around.	- micro-CT 3D printed models - whiteboard -marker -Leaves -flowers -projector screen
Instructional Activities *Time: 30 min*	*Flower Identification:* Pass out little eyepieces to all of the students so that they will be able to see the floral structures. While everyone is looking at the same species, point out each organ. We begin with sepals and petals because they are the most obvious. Then, we move on to the stamen, which is composed of the anther and filament. Next, go to the pistil, composed of the stigma, style, and ovaries. Discuss the concept of a floral formula. This formula is used to record the number of sepals, petals, floral symmetry, number of carpels, and number of stamens in a species. Which further differentiates families and how to quickly identify a flower family based on floral formula knowledge. Teach students how to press their favorite flowers. Students will pick out a flower and then press it to dry and store it. *3D-Leaf model building:* Break students into groups so that they can work collaboratively. Supply a plexiglass box and an assortment of other materials such as Styrofoam squares, Styrofoam balls, organized grid-like material for palisades, cardboard, sticks, and tubing for vessels. Have students work together to build a 3D model of a leaf in the correct order. With	- Eyeglasses -Flowers -cardboard -newspaper -strap -plexiglass box -Styrofoam balls -Styrofoam rectangle -cardboard -paper -branches

	a lower epidermis that is densely packed with stomates. Above this layer will be Styrofoam balls of different sizes to represent the spongy mesophyll. Above this layer will be a thick Styrofoam rectangle, which will represent the palisade mesophyll. Then, cardboard on top to represent the upper epidermis and a thin cuticle layer of paper. Add sticks for trichomes.	
Wrap Up, Synthesis/Closure *Time: 10 min*	-Discuss how all of these traits we looked at today allow plants to take water from the soil. The spongy mesophyll provides air pockets of low carbon dioxide concentration to gain carbon dioxide. During this exchange considerable amounts of water are lost through the stomata pore. This evaporation at the leaf surface provides an extreme pressure gradient from roots to leaves, driving the conduction of water. A rubber band is a great tool to show the tension in the xylem when water is being pulled. *Exit slip:* How many different cell types compose a leaf and label them.	-Rubber band

Resources:
https://purdue0-my.sharepoint.com/personal/irimer_purdue_edu/Documents/Courses/Spring%202024/ASEC%2054500/Mini%20unit/Lecture%20One.pptx

Lesson 2: Plant Water Relations

Est. Time: 55 minutes

Lesson Learning Goals/Objectives:	Standards:
1. A student should be able to identify and explain the importance of a stoma. 2. Students will be able to calculate stomata density. 3. Students will be able to explain how water potential differences drive how plants take water. 4. Students will be able to describe the relationship between stomata/guard cells and epidermal cells and articulate the hydro-active force necessary.	PS.01.01. Determine the influence of environmental factors on plant growth. PS.01.01.03.b. Analyze and describe plant responses to water conditions PS.01.01.03.c. Analyze plant responses to water conditions and recommend modifications to water for desired plant growth. PS.01.02.02.c. Determine the hydraulic conductivity for soil and how the results influence irrigation practices. PS.02.03.01.b. Apply knowledge of photo-synthesis to analyze how various environmental factors will affect the rate of photosynthesis.

	HS-LS1-5 Use a model to illustrate how photosynthesis transforms light energy into stored chemical energy. 4-PS3-2 Make observations to provide evidence that energy can be transferred from place to place by sound, light, heat, and electric current 3-5-ETS1-3 Plan and carry out fair tests in which variables are controlled, and failure points are considered to identify aspects of a model or prototype that can be improved. 8.C.1: Solve real-world problems with rational numbers by using multiple operations 3.NS.4: Use fraction models to represent two simple equivalent fractions with attention to how the number and size of the parts differ even though the quantities are the same. 3.CA.5: Multiply and divide within 100 using strategies such as the relationship between multiplication and division 4.NS.3: Use fraction models to represent two equivalent fractions with attention to how the number and size of the parts differ even though the fractions themselves are the same size 4.CA.5: Solve real-world problems with whole numbers involving multiplicative comparison 5.CA.2: Solve real-world problems involving multiplication and division of whole numbers

Assessments

Pre-Assessment:

- Exit and admit slip.

Formative:

- Who can tell me the role of the stomata?
- How is water lost from the leaf?
- How would one calculate the density of a whole leaf or canopy from single impressions?
- Who can tell me what causes stomata to close?
- Can someone explain the hydro-active force?

Summative:

- Exit ticket

Concept Prerequisites or Background Knowledge Needed:

- Basic math (Arithmetic)
- Lesson one

Vocabulary:

Xylem, phloem, stomata, cells, mesophyll, epidermis, trichome, vessels, potential, density, force, water potential, hydro-active, and osmosis

Materials & Technology Needed:

Clear nail polish, microscopes, bike tire tube, zip ties, potato core, water, salt, cups, something to take notes of observations, and leaf material.

Lesson Component	Instructions	Materials
Introduction *Time: 10 min*	*Pre-Assessment:* - Entry Ticket *Introduction:* -Discuss the plan and goals for the lesson *Review:* -Review Previous topics from the last class	-Projector Screen -Projector
Instructional Activities *Time: 35 min*	*Potato Activity:* Have students perform serial dilutions; there will be one cup of just water, next of a medium saltwater solution, and then a high saltwater solution. Have students make observations of the potato cores before they are submerged in the different water solutions. Then, have students make a hypothesis about what will happen to each peel. Move to the stomata impression activity to wait. Once returned, take the potato cores out of the water solution. Have students record their observations. Were the students right? The core in the solution with just water should have much more turgor compared to the saltwater solution cores. This is a great activity to talk about osmosis and the movement of water across membranes. *Stomata Impressions and movement:* Bring in a supply of leaves from native trees in the surrounding area. Teach students how to perform stomata impressions on the abaxial surface of leaves. Place a small amount of nail polish on a glass slide, and quickly press the abaxial surface of the leaf on the nail polish. Allow the nail polish to dry, and gently peel away the leaf. Have students perform this activity with a variety of species brought in. Have students label slides to keep track of species. With the microscopes, student will look at their samples. They will be able to see clear epidermal and stomatal cells from their impressions. Ask them what they notice across species. Ask students how they would go about counting the number of stomata on a whole leaf, then a whole tree. Explain why water loss becomes such a great problem at this whole tree scale.	-Potato cores -Cups -Water -Salt -clear nail polis -glass slides -microscopes -Projector Screen -Projector -Whiteboards -Marker
Wrap Up,	*Bike tire:*	-Bike tire tube

Synthesis/Closure *Time: 10 min*	Tie the two ends of the flaccid bike tire tube together with zip ties. Explain why when leaves lose turgor, become wilt, their stomata close (either passively or due to ABA production). But when water is available, the guard cells of the stomata have to push back against the now fully turgor epidermal cells to open. Begin pumping up the bike tire. The apex reasons of the bike tire will eventually buckle, causing an opening to occur in the bike tire tube. This is a great example of the hyperactive force in stomata guard cell opening. *Exit slip:* - Have students fill out an exit slip.	-Pump -Zip-ties

Resources:

https://purdue0-my.sharepoint.com/personal/irimer_purdue_edu/Documents/Courses/Spring%202024/ASEC%2054500/Mini%20unit/Lecture%20Two.pptx

Lesson 3: Plant Hydraulic Project

Est. Time: 55 minutes

Lesson Learning Goals/Objectives:

1. Students will be able to apply knowledge from previous lessons to construct and design an efficient model of the plant hydraulic network.
2. Evaluate the design and find room for improvements.
3. Students will be able to describe variations in force through transpiration at the leaf surface to drive water movement in a natural setting.

Standards:

PS.04.02.01.a. Research and summarize the principles and elements of design for use in plant systems.

3-5.E.1. Identify a simple problem with the design of an object that reflects a need or a want. Include criteria for success and constraints on materials, time, or cost.

Assessments

Formative:
What does engineering design entail?
What are plant traits that you will consider when designing your system?
What does the syringe represent in the plant system?

Summative:
Final Test

Concept Prerequisites or Background Knowledge Needed:
Lessons One and Two

Vocabulary:
Hydraulics

Materials & Technology Needed:
Straws, connector tubes, tubing, parafilm, projector, projector screen, cups, and water

Lesson Component	Instructions	Materials
Introduction *Time: 5min*	*Review:* -Ask the class if they can summarize what they have learned in the previous two lessons. *Introduction:* -Introduce the criteria for the hydraulic network project	-Projector Screen -Projector
Instructional Activities *Time: 20 min*	*Plant Hydraulic Project:* Students will be divided into teams and asked to construct their own plant hydraulic network. Straws of varying width and lengths will be provided to the students. Students will then have to figure out how to hold all the straws together. A water source 4 straw lengths away will be placed for teams to set their straws in. Students will attempt to draw water from the reservoir with a syringe and determine who can empty their reservoir first. Students will compare results with materials used and discuss the benefits and limitations of their choices.	-Coffee and other straws of varying width and cut to varying sizes (thicker tubes will be shorter with more restricted junction points to represent gymnosperms, while longer thinner tubes with few junctions will represent angiosperms.) -connectors -tubing
Wrap Up, Synthesis/Closure *Time: 10* **Final Assessment:** *Time:* 20	*Reflection* -Ask the students what they have learned from this activity. -Ask students what they would change about their designs. *Final Assessment*	NA

Resources:
https://purdue0-my.sharepoint.com/personal/irimer_purdue_edu/Documents/Courses/Spring%202024/ASEC%2054500/Mini%20unit/Lecture%20Three.pptx

Assessment Plan

The Plumbing of Plants

The Target Audience consists of grade School Students (4-6) who have completed the unit in a formal classroom setting.

Objective Assessed:

- Explain and identify different organs of a plant.
- Students will be able to use math to quantify various plant properties and make inferences on performance.
- Students will be able to describe how plants respond to environmental stimuli.
- Scholars will be able to explain different agricultural management practices.

Instructions:

- Students will answer pre-assessment questions at the beginning of class and answer questions throughout the lesson in order to spark further discussion.
- Students will complete entry and exit tickets for each lecture to gauge the student's initial understanding and the effectiveness of the lesson.

Total Points:

- Not graded and or participation points for attending the lessons.

Formative Assessments Overview

Pre-assessment questions and questions within the lessons

- Lesson One
    - *o* Ask students, “Can anyone tell me what they know about plants?” and wait for responses. The next question builds off the presentation, where the educator will ask the class if they can identify the different parts of a tree. Then, moving into the Hagen-Poiseuille equation, the educator will ask the students, based on the radius of the xylem, which species have a greater flow rate. After building the leaf model, the class will then be asked if they can recall what each cell of the leaf is called. The lecture will end with an open question asking students, “Does anyone know how plants take water from the soil?”. Wait for a response, but do not give an explanation. Let students think about water relations until the next lecture.

- Lesson Two

    - Lesson two will begin with the same question as the end of lesson one: “Does anyone know how plants take water from the soil?”. Wait for a response, and then ask the students what they know about stomates. After the introduction of the potato activity and the students' making their hypothesis, the lesson will move on to examining stomata impressions. Students will be asked to determine the stomata density from a specific image and explain why they chose their specific procedure. Students will then be asked if they can explain how stomates respond to environmental stimuli. After the turgor loss point activity with soil water management plans and the bike tire tube demonstration, students should be asked if they can explain the hydro-active force. Wait for a buckling response or push against the epidermal (puzzle) cells.

- Lesson Three
    - Lesson three involves the construction of the plant's hydraulic network. Students will be asked what the engineering design process is and how it relates to the current project. At the end of the project, students will be asked to reflect on their design process and ask what could have been done to make their design better.

Entry and Exit Tickets: The educator will pass out notecards at the beginning and end of each lesson to gauge students' initial knowledge and how much they gained throughout the lesson.

Lesson One

- The entry ticket will be a picture of a tree with blank spaces for the students to then fill out. The same image will be used at the end of the lesson to determine how much information the students retained.

Lesson Two

- For Lesson Two, there are two questions to gauge the student's initial understanding of stomata and plant water relations. The first question asks, “What is the role of the stomata?” while the second question asks, "Where does water move?”.

Summative Assessments Overview

The Plumbing of Plants

The Target Audience consists of grade School Students (4-6) who have completed the unit in a formal classroom setting.

Objective Assessed: In this test, students will demonstrate an understanding of:

- Identify the anatomy of a plant, leaf, flower, and stem.
- Identify how plant morphology and physiological response are related.
- Be able to calculate quantitative plant characteristics.
    - Flow rate, stomata density, estimation of canopy water loss.
- Explain how quantifiable plant characteristics are used in the agricultural setting for more effective management.
- Explain a plant's water potential and how this relates to how plants extract water from the soil.
- Explain how plants cope with drought.

Total Points:

- 100 points

Instructions for students:

- Follow directions on the handout and stated by the educator.

Example Test:

- Final Test

Rubric for Educator

- Test Answers

Summative Assessment Tool for Knowledge Outcomes:

- The final assessment in the “Plumbing of Plants” unit will be a comprehensive assessment, connecting the goals and objectives outlined in lessons one through three. This test will use multiple choice, matching, fill-in-the-blank, free response, and a drawing section to test students' comprehension from the previous lessons. The summative assessment will determine how much of the content the students actually retained. Further, questions from this summative assessment can be utilized in a larger unit overview such as a final.

Assessment connection to unit objectives

1. Identify Plant anatomy (i.e., plant, stem, and leaf).
    - Formative through entry and exit ticket,
    - Formative through in-class questions.
    - Summative assessment at the end of the unit.
2. Explain the importance of flow rate and vessel diameter.
    - Formative through in-class questions.
    - Summative assessment at the end of the unit.
3. Explain that variation in anatomy causes variation in water transport.
    - Formative through in-class questions.
    - Continuous assessment
    - Summative assessment at the end of the unit.
4. Describe the importance of cellular locations in the anatomy of a leaf.
    - Formative through entry and exit ticket.
    - Formative through in-class questions.
    - Summative assessment at the end of the unit.
5. Explain the importance of a stoma.
    - Formative through entry and exit ticket.
    - Formative through in-class questions.
    - Summative assessment at the end of the unit.
6. Use mathematics to quantify plant characteristics.
    - Formative through in-class questions.
    - Formative through in-class problems.
    - Continuous assessment.
    - Summative assessment at the end of the unit.
7. Describe how variation in water potential drives plant water uptake.
    - Formative through entry and exit ticket.
    - Formative through in-class questions.
    - Summative assessment at the end of the unit.
8. Explain why taking into consideration the physiological properties of plants is important in agricultural management.
    - Formative through in-class questions.
    - Formative through in-class problems.
    - Summative assessment at the end of the unit.
9. Design an agricultural management irrigation plan based on stomata closure.
    - Formative through in-class problems.
    - Summative assessment at the end of the unit.

Physical Materials for Lessons and Activities

Lesson One

- Models of Xylem anatomy from different species
- Whiteboard
- Marker
- Leaves
- Flowers
- Projector screen
- Forceps
- Eyeglasses
- Cardboard
- Newspaper
- Strap
- Plexiglass box or cup
- Styrofoam balls or marbles
- Styrofoam rectangle
- Paper
- Branches
- Rubber Band

Lesson Two

- Projector screen
- Potato cores
- Cups
- Water
- Salt
- Clear nail polish
- Slides
- Some microscope lens
- Whiteboard
- Markers
- Bike tire tube
- Pump
- Zip ties

Lesson Three

- Projector screen
- Tubing of varying width
- Straws of varying width
- Connector pieces
- Parafilm
- Syringe
- Cup
- Water

Standards

Lecture 1

- 5-LS1-1: Support an argument that plants get the materials they need for growth chiefly from air and water.
- 5-LS2-1: Develop a model to describe the movement of matter among plants, animals, decomposers, and the environment.
- PS.02.01.01.a. Identify and summarize systems used to classify plants based on specific characteristics
- PS.02.02.02.a. Identify and summarize the components, the types and the functions of plant roots.
- PS.02.02.04.a. Research and summarize leaf morphology and the functions of leaves
- PS.02.02.03.c. Evaluate the function of the xylem, phloem and cambium tissues and the impact on plant systems.
- PS.02.02.05.a. Identify and summarize the components of a flower, the functions of a flower and the functions of flower components.
- 4-LS1-1: Essential Construct an argument that plants and animals have internal and external structures that function to support survival, growth, behavior, and reproduction.
- 3.CA.3: Model the concept of multiplication of whole numbers using equal-sized groups, arrays, area models, and equal intervals on a number line.
- 3.CA.5: Multiply and divide within 100 using strategies such as the relationship between multiplication and division
- 4.NS.3: Use fraction models to represent two equivalent fractions with attention to how the number and size of the parts differ even though the fractions themselves are the same size
- 4.CA.5: Solve real-world problems with whole numbers involving multiplicative comparison
- 4.M.3: Use the four operations to solve real-world problems involving distances, intervals of time, volumes, masses of objects, and money.

- 5.CA.2: Solve real-world problems involving multiplication and division of whole numbers

Lecture 2

- PS.01.01. Determine the influence of environmental factors on plant growth.
- PS.01.01.03.b. Analyze and describe plant responses to water conditions
- PS.01.01.03.c. Analyze plant responses to water conditions and recommend modifications to water for desired plant growth.
- PS.01.02.02.c. Determine the hydraulic conductivity for soil and how the results influence irrigation practices.
- PS.02.03.01.b. Apply knowledge of photosynthesis to analyze how various environmental factors will affect the rate of photosynthesis.
- HS-LS1-5 Use a model to illustrate how photosynthesis transforms light energy into stored chemical energy.
- 4-PS3-2 Make observations to provide evidence that energy can be transferred from place to place by sound, light, heat, and electric current
- 3-5-ETS1-3 Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.
- 8.C.1: Solve real world problems with rational numbers by using multiple operations
- 3.NS.4: Use fraction models to represent two simple equivalent fractions with attention to how the number and size of the parts differ even though the quantities are the same.
- 3.CA.5: Multiply and divide within 100 using strategies such as the relationship between multiplication and division
- 4.NS.3: Use fraction models to represent two equivalent fractions with attention to how the number and size of the parts differ even though the fractions themselves are the same size
- 4.CA.5: Solve real-world problems with whole numbers involving multiplicative comparison

- 5.CA.2: Solve real-world problems involving multiplication and division of whole numbers

Lecture 3

- PS.04.02.01.a. Research and summarize the principles and elements of design for use in plant systems.

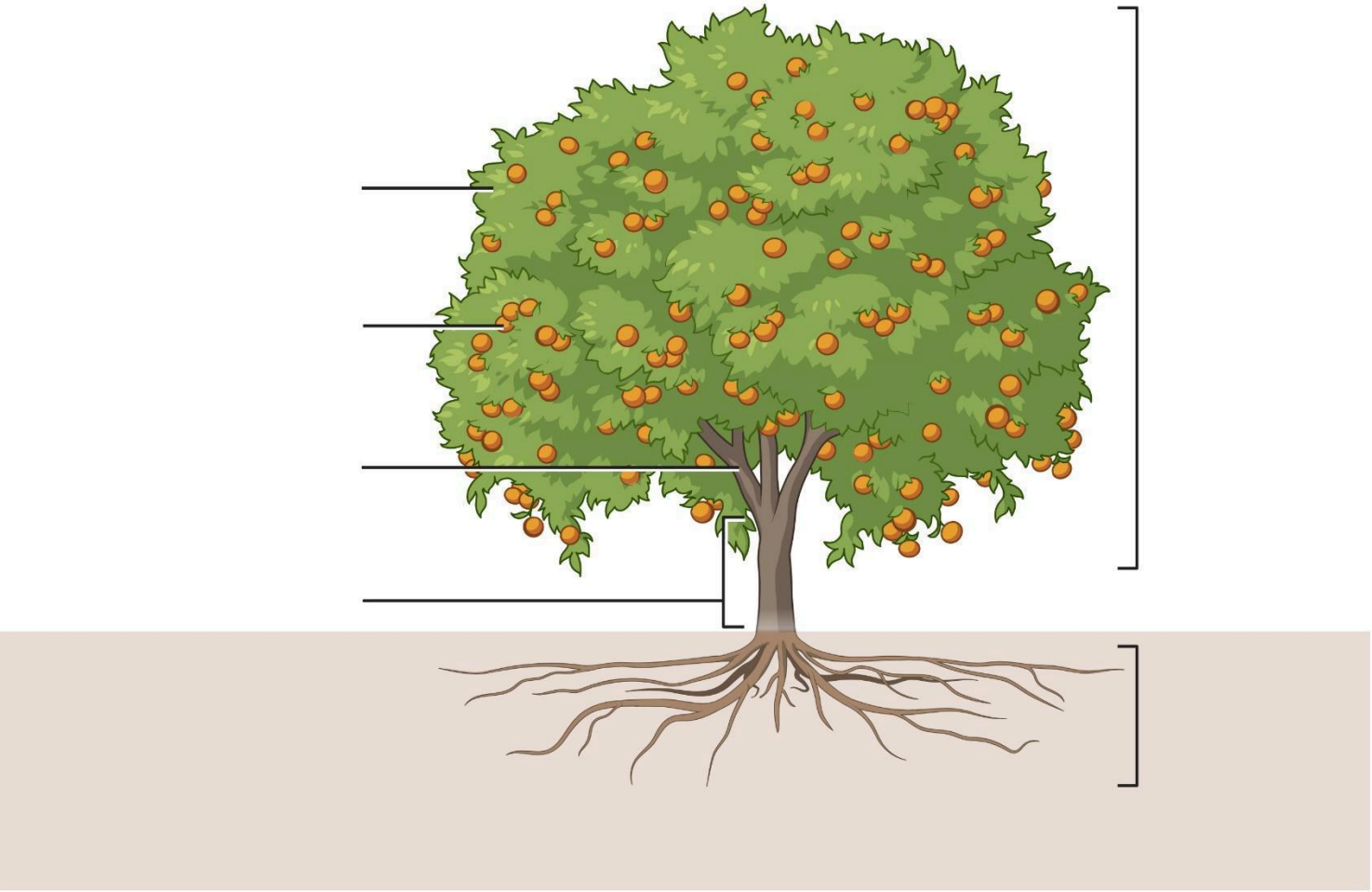
- 3-5.E.1. Identify a simple problem with the design of an object that reflects a need or a want. Include criteria for success and constraints on materials, time, or cost.

Appendix

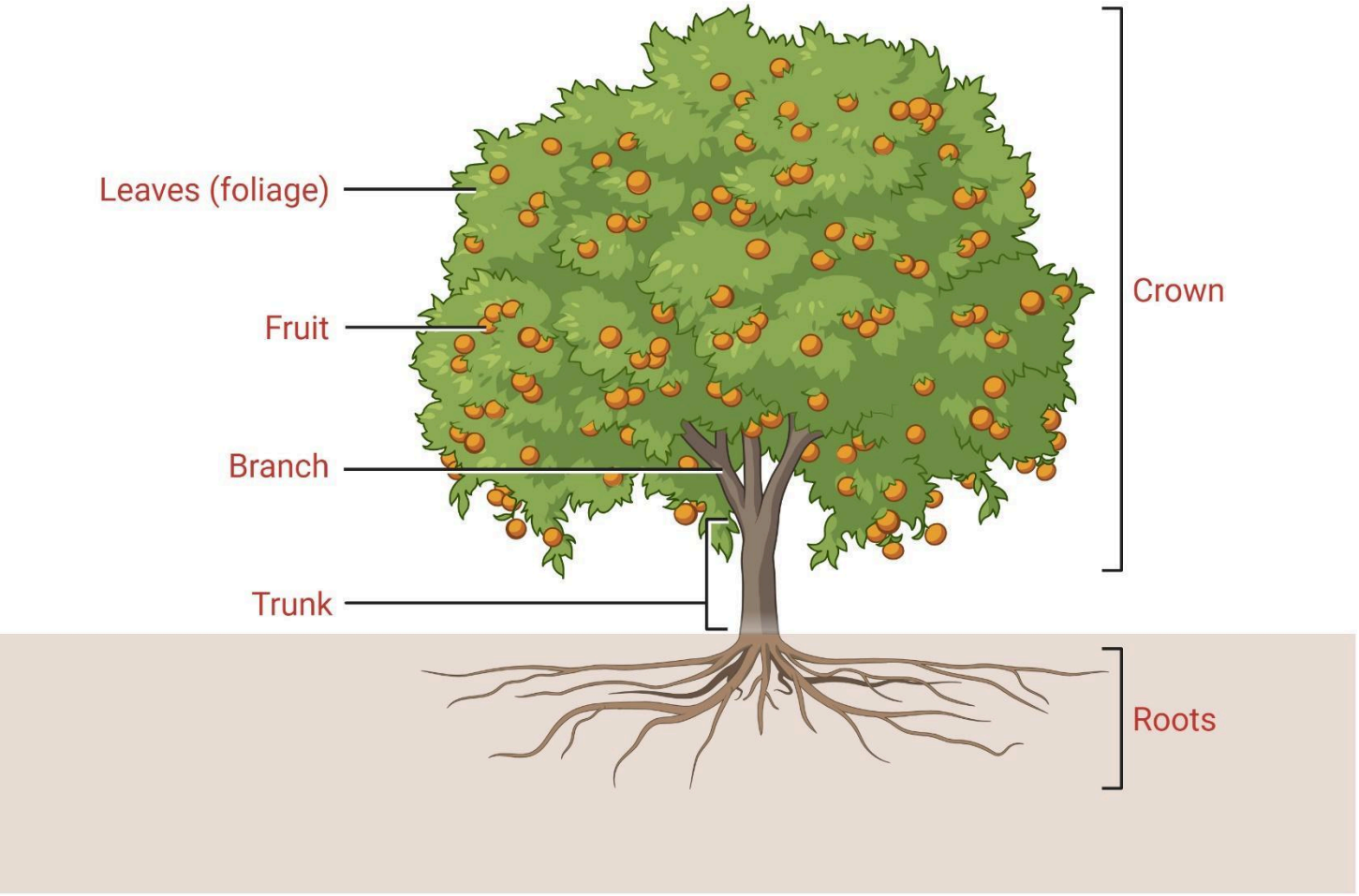
Lesson One

Lecture One: Entry Ticket

Lecture One: Exit Ticket

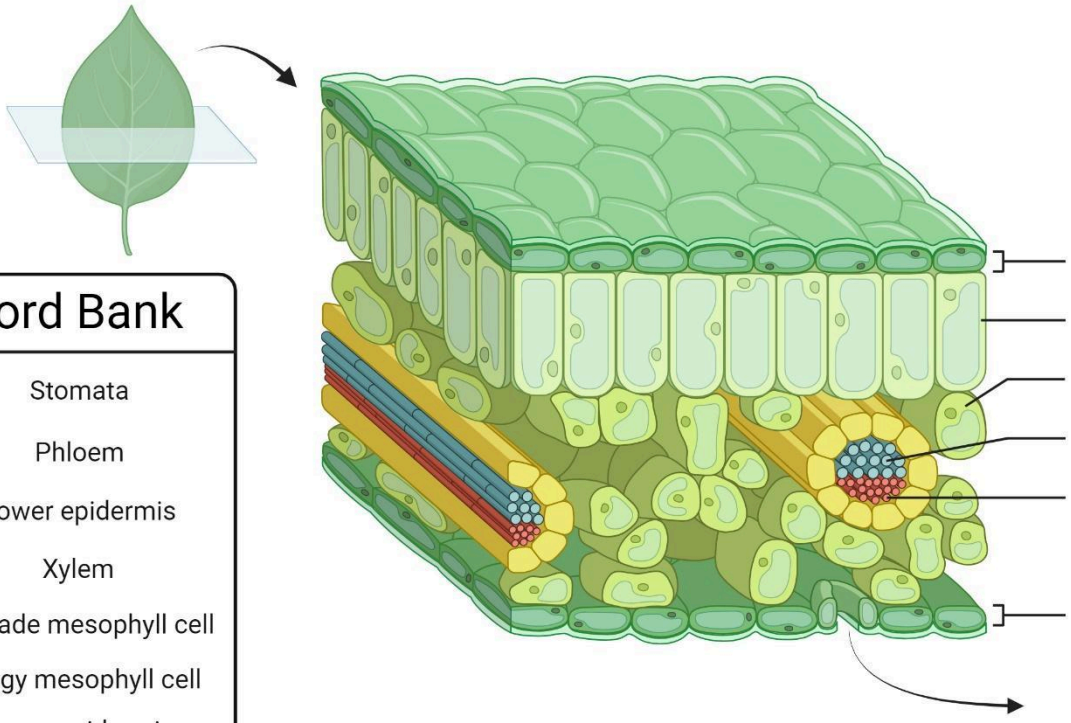


Lecture One: Entry and Exit Ticket Answers



Lecture One: Quiz

Leaf Cross-Section (3D)



Word Bank

Stomata

Phloem

Lower epidermis

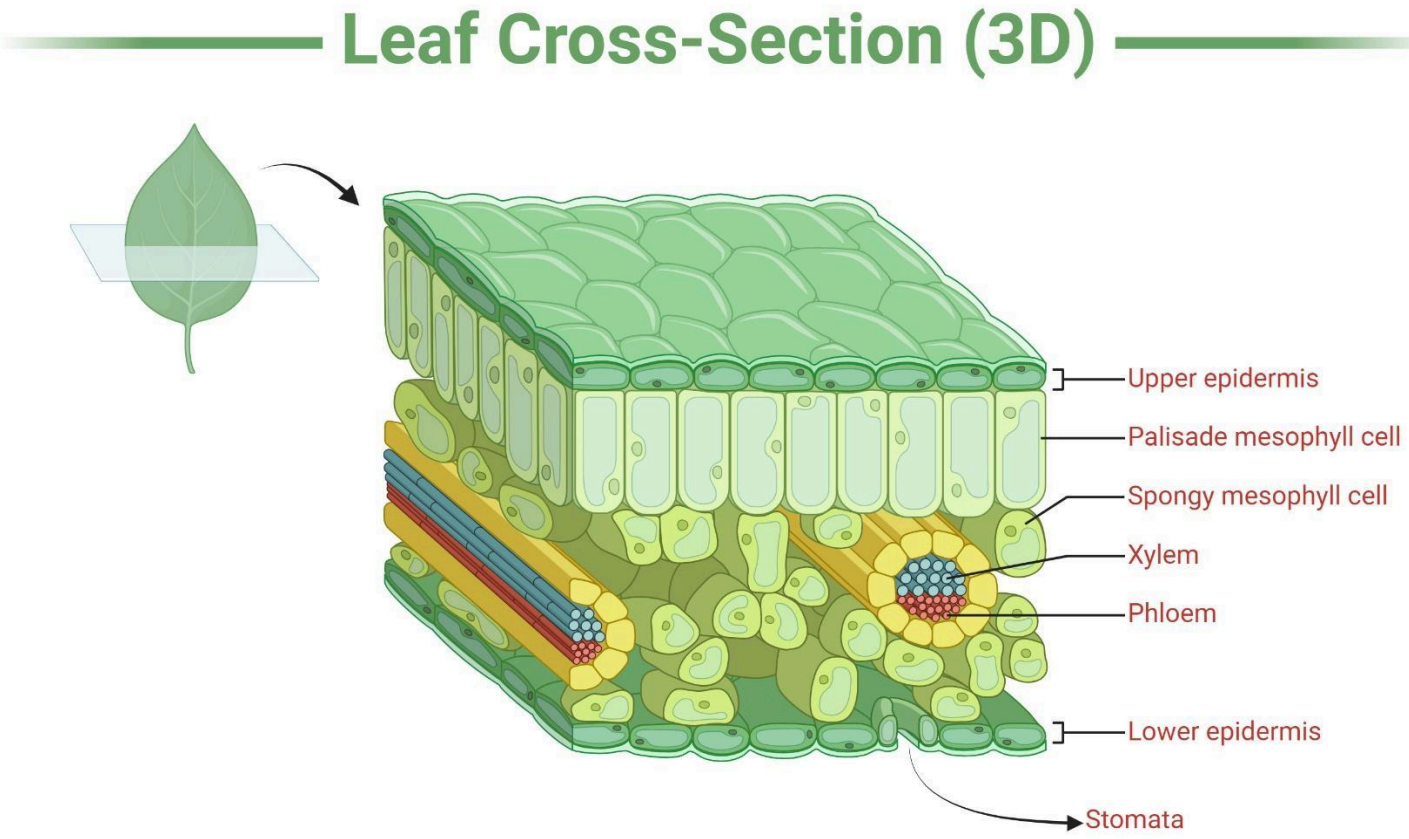
Xylem

alisade mesophyll cell

pongy mesophyll cell

Upper epidermis

Lecture One Quiz Key



Lesson Two

Entry Ticket:

What is the role of the stomata?

1. Allow light to enter into the leaf
2. Absorb water from the atmosphere
3. Controls the rate of carbon dioxide intake and water loss
4. Mutations from the epidermal cells

Where does water move?

1. Water does not move
2. Low water potential to high water potential
3. High water potential to low potential
4. Water fluctuates across the plant evenly

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Entry/Exit Ticket Answers
Entry Ticket:

What is the role of the stomata?

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Where does water move?

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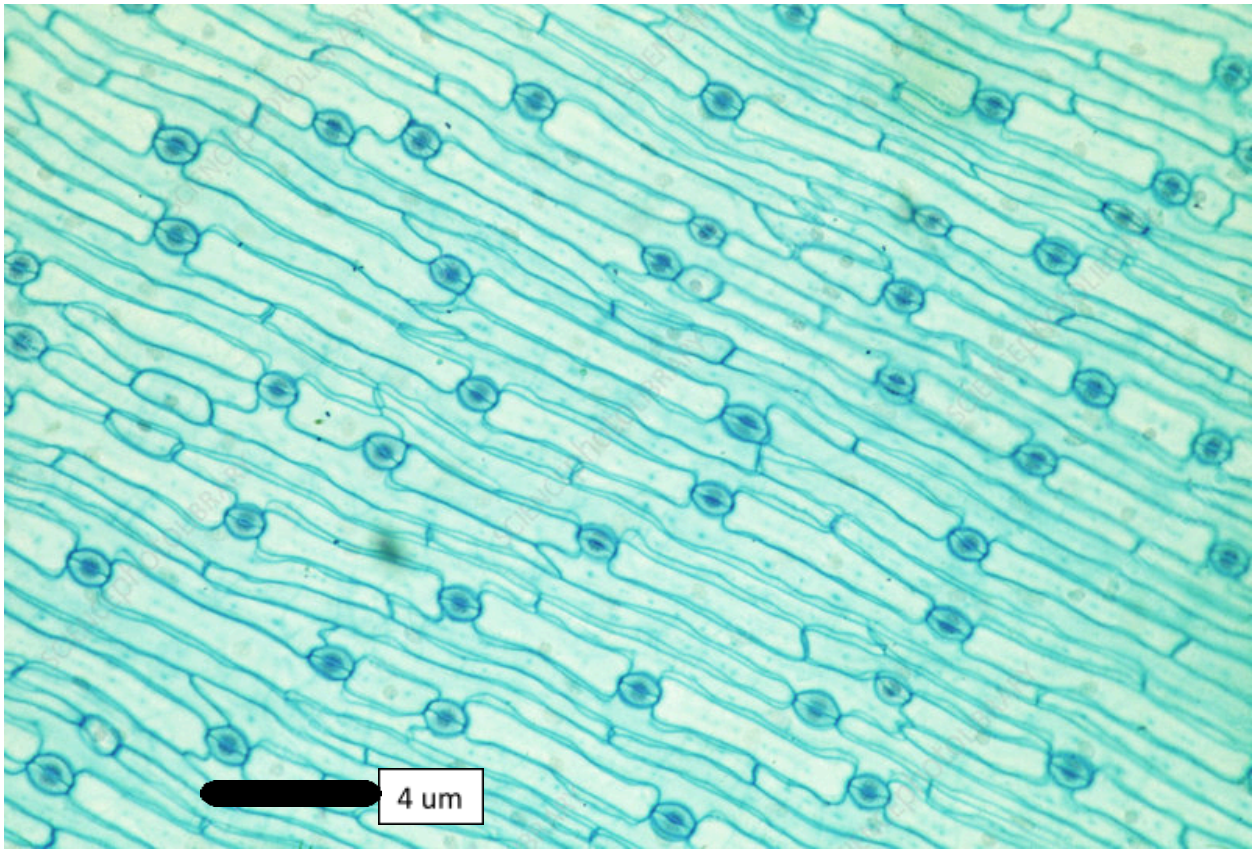
Questions to provide scholars are on the next three pages for lesson two.

1. What is the stomata density of this image?



Answer to the stomata density question image. From question one.

1. What is the stomata density of this image?

Image is 8 um x 6 um

Area is 48 um

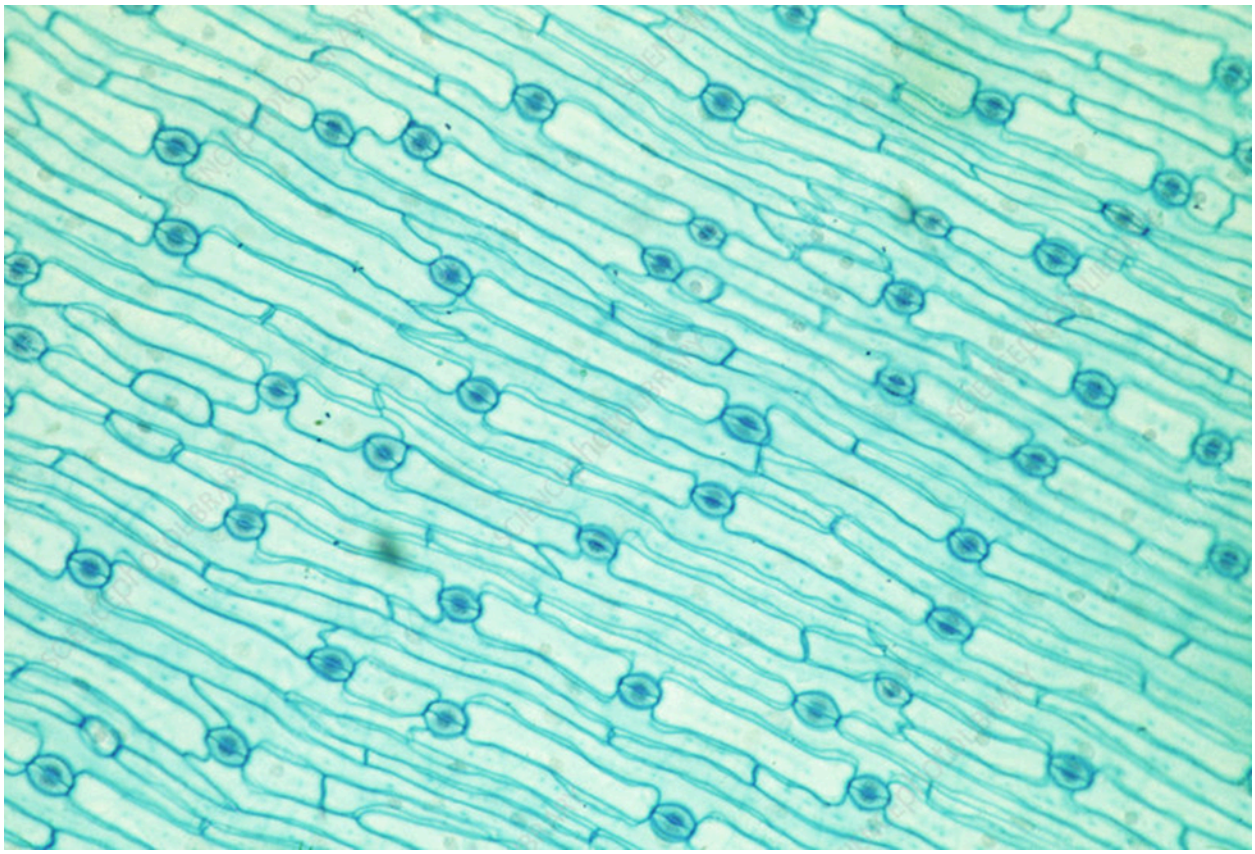
Number of stomates = 48

Density = $\frac{Number\ of\ Stomates}{Area}$

Density = $\frac{48\ stomates}{48\ um}$

Density = 1 $\frac{stomate}{um}$

2. If a stomate loses a million water molecules an hour, how many water molecules are lost through the image below in 4 hours?



Answer to how many water molecules are lost question? From question two.
192,000,000 water molecules

3. Using your answers from the previous two questions, answer the following questions 1 and 2.

If the canopy leaf area in a corn field is 200,000 m^2, estimate how many stomata there are.

Answer to question three.

200,000 stomates

Lesson Three

The Assessment in Lesson Three will be the final assessment.

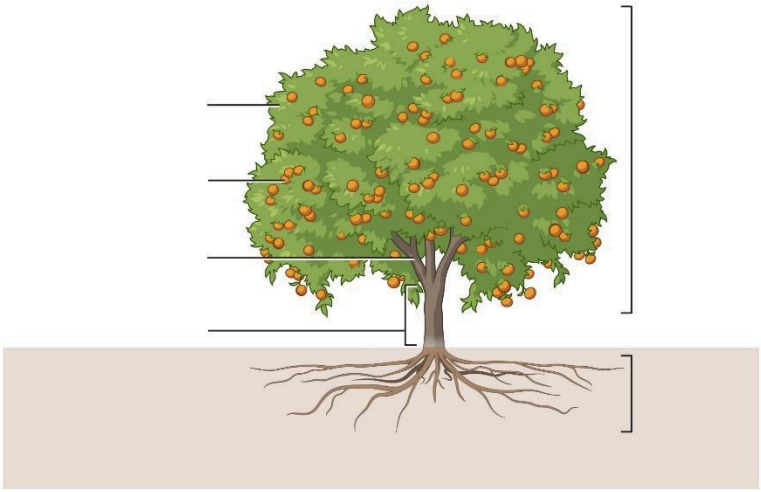
Final Assessment begins on the next page

The Plumbing of Plants Test

5 points a question, 20 questions.
Total points: 100 points

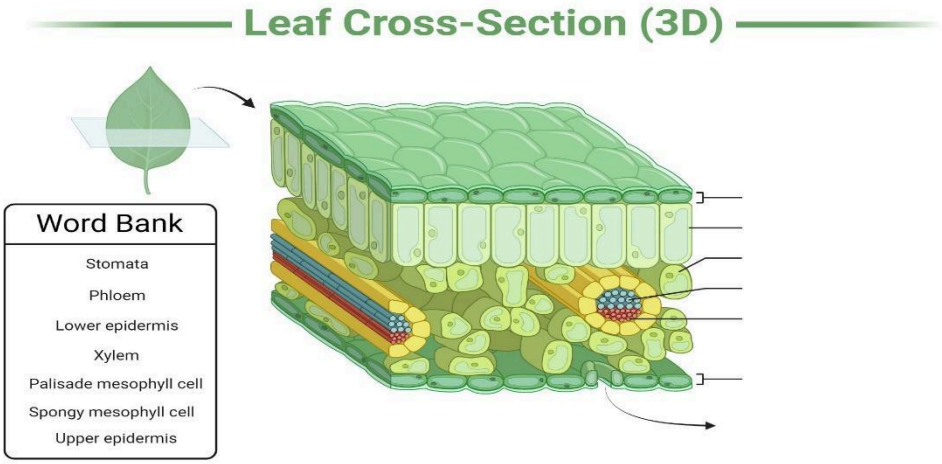
Name: _____

1. Fill in the blanks in the following image with the given word bank.



Word Bank:
- Leaves
- Fruit
- Arm
- Branch
- Crown
- Base
- Trunk
- Vegetable
- Bark
- Soil
-

2. Fill in the blanks in the following image with the given word bank.



3. What is the role of the stomata?

    a. Allow light to enter into the leaf.
    b. Absorb water from the atmosphere.
    c. Controls the rate of carbon dioxide intake and water loss.
    d. Mutations from the epidermal cells

4. Where does the water move?

    a. Water does not move.
    b. Low water potential to high water potential
    c. High water potential to low potential
    d. Water fluctuates across the plant evenly.

5. What does the Hagen-Poiseuille Equation provide?

    a. Flow of water
    b. Acceleration of water
    c. Temperature of water
    d. Area that water moves through.

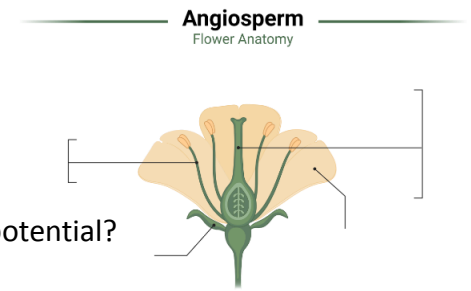
6. What is the vessel that is critical for the acquisition of water.

    a. Phloem
    b. Xylem
    c. Root
    d. Branch

7. What does the S stand for in the floral formula.

    a. Petal
    b. Stamen
    c. Peta
    d. Sepal

8. Fill in the blanks in the following image with the corresponding blanks.



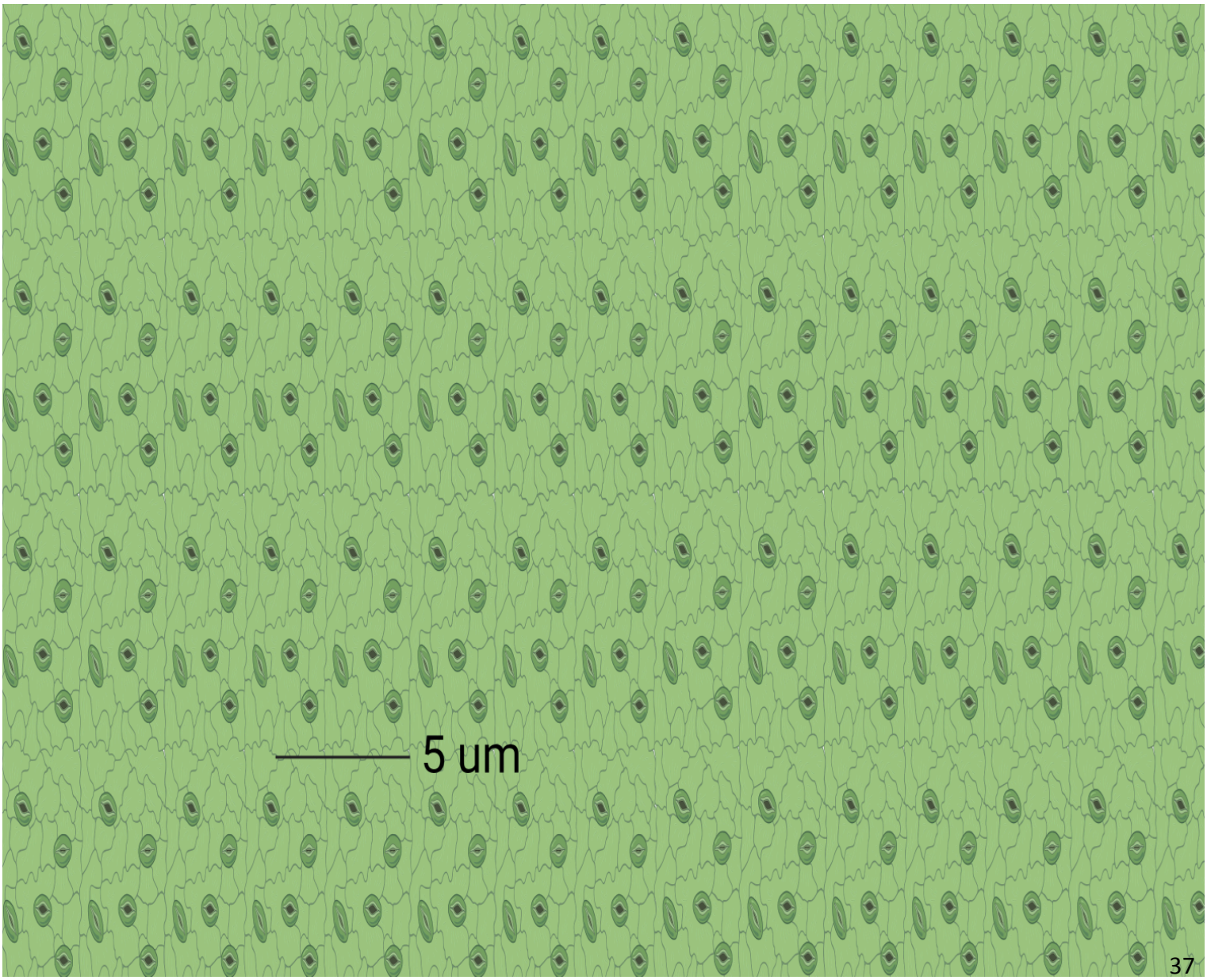
9. What is the water potential?

a. The potential energy of water to do work.
b. The potential energy of sugar in the water to do work.
c. The degree of wetness in the water
d. How much water is stored in the plant.

10. What is the role of water potential in a plant?

a. How much water goes through it.
b. Determine the volume of water in the plant.
c. Quantifies the tendency of water to move from one area to another.
d. The water potential that supports photosynthesis

11. Estimate the stomata density in this photo.



12. What byproduct of plants do humans utilize.

a. Water
b. Oxygen
c. Carbon dioxide
d. Hydrogen Peroxide

13. When stomata open what do they have to push against

a. Guard cells
b. Vessels
c. Epidermal Cells
d. Mesophyll Cells

14. Why are the airspaces in between the mesophyll cells

a. To allow plants to breath
b. Allow for the diffusion of carbon dioxide into the plant
c. Inhibit the loss of water through the stomata
d. To keep the leaf together through cohesive properties

15. Which cells in the leaf do the majority of photosynthesis

a. Epidermal cells
b. Mesophyll cells
c. Palisade cells
d. Photosynthetic cells

16. How do plants respond when water is limiting?

a. Grow more roots to find more water
b. Close their stomata to prevent water loss
c. Obtain water from the air
d. Die

17. True or False?

Larger stomates will lose more water than smaller stomates during transpiration.

18. Answer the following questions to this paragraph.

A few scientists went out last summer to collect some data of a few native Indiana tree species. The list of tree species they surveyed consisted of White oak (Quercus alba), Black cherry (Prunus serotina), Basswood (Tilia americana), and Sugar maple (Acer Saccharum). The scientists measured the radius of the xylem, xylem length, density of the stomates, and the water potential at stomatal closure across all species. In Table 1.0 you will find the values for each variable found across all species.

Table 1.0

Species	**Xylem Radius (um)**	**Xylem length (cm)**	**Stomatal density** $(\frac{stomates}{1\ cm^2})$	**Turgor Loss Point (MPa)**
White oak (*Quercus alba*)	3	120	125	-1.8
Black cherry (*Prunus serotina*)	6	65	346	-1.1
Basswood (*Tilia americana*)	1	67	67	-2.4
Sugar maple (*Acer Saccharum*)	15	24	214	-1.4

1. Which species has the greatest flow rate? (1 point)

_____

_____

2. Which species closes their stomata first during a drought? (1 point)

_____

_____

3. Which species loses the most water during transpiration? (3 points)

_____

_____

19. How is the floral formula used to classify plants into families in order to make a phylogeny?

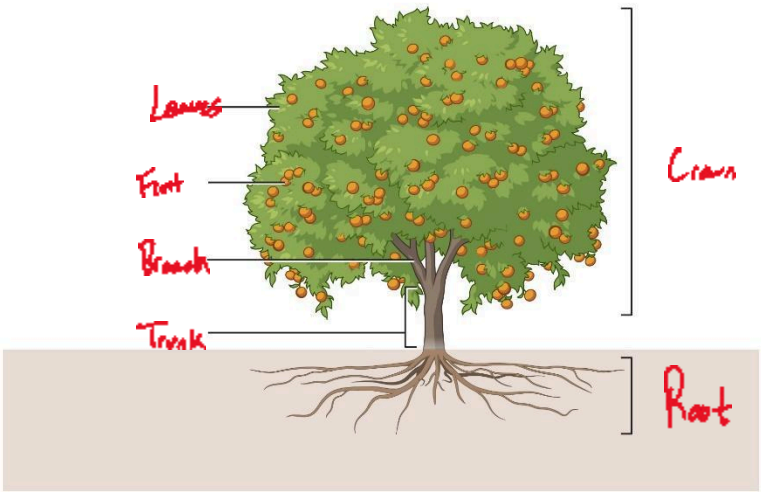
20. Write in a few sentences how plants obtain water from the soil?

The Plumbing of Plants Test

5 points a question, 20 questions.
Total points: 100 points

Name: __Answers_____

21. Fill in the blanks in the following image with the given word bank.



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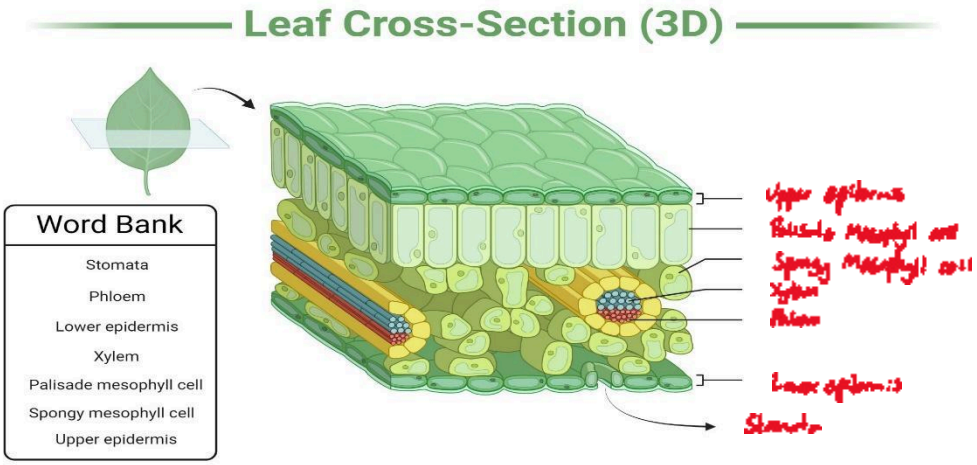

23. What is the role of the stomata?

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b. Absorb water from the atmosphere.
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24. Where does the water move?

a. Water does not move.
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25. What does the Hagen-Poiseuille Equation provide?

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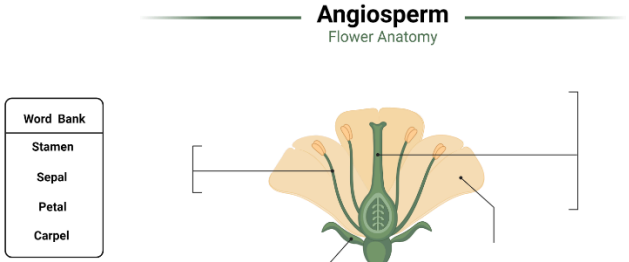

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31. Estimate the stomata density in this photo.

32. What byproduct of plants do humans utilize.

a. Water
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33. When stomata open what do they have to push against

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35. Which cells in the leaf do the majority of photosynthesis

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b. Mesophyll cells
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36. How do plants respond when water is limiting?

a. Grow more roots to find more water
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c. Obtain water from the air
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37. True or False?

Larger stomates will lose more water than smaller stomates during transpiration.

38. Answer the following questions to this paragraph.

A few scientists went out last summer to collect some data of a few native Indiana tree species. The list of tree species they surveyed consisted of White oak (Quercus alba), Black cherry (Prunus serotina), Basswood (Tilia americana), and Sugar maple (Acer Saccharum). The scientists measured the radius of the xylem, xylem length, density of the stomates, and the water potential at stomatal closure across all species. In Table 1.0 you will find the values for each variable found across all species.

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4. Which species has the greatest flow rate? (1 point)

Acer Saccharum

5. Which species closes their stomata first during a drought at MIGGS farm? (1 point)

Prunus serotina

6. Which species loses the most water during transpiration? (3 points)

Prunus serotina

39. How is the floral formula used to classify plants into families in order to make a phylogeny?

The floral formula is a symbolic representation of the structure of a flower using lesser, numbers and symbols.

Floral formula are used to phylogenetically differentiate families.

40. Write in a few sentences how plants obtain water from the soil?

Due to high humidity in the mesophyll, water is pulled from the leaf from the atmosphere, causing a water potential gradient across the plant. Due to the high water potential of the soil, water travels through the plant, to the evaporating surface of a leaf.

Potential Worksheet Examples

Lesson One

A farmer has four different fields that are irrigated through wetlands, city water, well water, or not irrigated at all. The farmer has asked you to collect some data and determine which water management strategy would be most effective. You have decided to collect data on photosynthetic rates, yield at the end of the harvest season, and costs.

Site	**Photosynthetic rate** $\frac{umol\ CO_2}{m^2}$	**Yield** ($\frac{bushels}{acre}$)	**Costs ($)**
Wetlands	14	562	1523
City Water	12.4	302	1825
Well Water	13.2	438	1297
Not Irrigated	10.4	254	503

Lesson Two

You are a scientist trying to determine the water use efficiency across a common range of crop plants. You have chosen to plant maize, soybeans, cowpeas, and sorghum. You have measured water loss rates and turgor loss points across each of the species and a series. Given the dataset in Table 1.0, devise an effective management strategy that is an efficient water management strategy.

Species	**Water Use Efficiency** $\frac{kg}{ha*mm}$	**Turgor Loss Point (MPa)**	**Water Potential at Death (MPa)**
Maize	40	-1.6	-2.1
Soybeans	32	-1.3	-1.9
Cowpeas	24	-0.95	-1.5
Sorghum	54	-2.5	-1.9

Given this dataset design and draw up an agricultural strategy on where you think it would be best to plant each of the species. Provide an irrigation strategy that would most effectively water your crops.

Timeline

Lesson One (55 min)

- Introduction and Pre-assessment: 5 min.
- Lecture: 10 min.
- Flower Identification: 15 min.
- 3D-Leaf model building: 15 min.
- Wrap-up Discussion: 5 min.
- Exit Slip: 5 min.

Lesson Two (55 min)

- Introduction and Pre-assessment: 5 min.
- Lecture: 10 min.
- Potato activity: 15 min.
- Stomata impressions: 15 min.
- Demonstration with bike tire tube: 5 min.
- Exit Slip: 5 min.

Lesson Three (55 min)

- Introduction and Pre-assessment: 5 min.
- Review: 5 min.
- Hydraulic Model Building: 35 min.
- Reflection: 5 min.
- Exit Slip: 5 min.

Learner-centered approaches to help learners apply the content.

Active learning approaches:

Lesson One

- Visual:
    - *o* A presentation that is accompanied by the lecture will provide visual quantification throughout the lecture. Within this lecture, there are many illustrations and videos for the students to watch to gain an initial idea of the topic. There will be simple illustrations showing the similarities between plants and human anatomy. Along with this lecture, there are different models of species in the surrounding area for the students to actually explore and see differences in internal plant structures. Further, a demonstration will be conducted by comparing white and red oaks. Obtain two sticks of white and red oak with no leaves. Ask the class if they think either one of these sticks can be used as a straw. The white oak has large vessels that allow the white oak stick to be used as a straw. This lesson also involves the dissection of flower material to examine the internal floral organs. This activity allows students to see, touch, and smell the different floral organs to gain a deeper understanding of the flower structure and what is needed for fertilization and fruiting in an agricultural setting. Lastly the students will design a model of a leaf so that they can put together each cellular layer of a leaf. This model will help students use and understand the engineering design process. Further, this will allow students to visualize the cellular components of a leaf.

- Verbal/Social:
    - *o* The Presentation will also be accompanied by questions throughout to gather students' responses and spark discussion. Initial questions will gauge how much the students know. Later questions will then test the student's comprehension of specific organs. When calculating the Hagen-Poiseuille equation, students will be able to see how small changes in the radius of the xylem cause large changes in the possible flow of water through the plant. The floral anatomy section will spark discussion on how flowers get pollinated and the mechanisms of actual fruit development. This will then lead to how fruit is produced and managed in an agricultural setting. Lastly, when building the leaf model, there will be a class discussion on the importance of each cell and questions as to why there is air space. This will spark discussion on the requirements of photosynthesis and its effects. This needs to be done at the end of the class so that there is a continuous lead into the next lecture on water relations.

Lesson Two

- Visual:
    - o A presentation that is accompanied by the lecture will provide visual stimulus throughout the lesson. The lesson begins with an observational experiment, where the students will determine the impact that varying salt concentrations have on a potato core. Potatoes are a common agricultural plant that the students should be familiar with and are a great

model for this demonstration. Students will take observations before the cores are placed in their corresponding solutions and then design a hypothesis on what they think will happen. At the end of the lesson, students will then reexamine the cores after they have been soaking for 30 minutes and determine if their hypothesis is correct or not. While the potato cores are soaking, students will then be introduced to stomata. Students will observe stomates through stomata impressions that they will make with different leaves. To explore how stomata actually open in response to the environment, a demonstration with a bike tire can be used. With this demonstration, a deflated bike tire will be tied on either side before pumping up with air. Once air is added, this will simulate the turgor pressure in the cells increasing in response to available water. At a specific threshold, the middle of the bike tire tubes will eventually buckle outwards, causing a gap between the two tires. This demonstrates that the increase in pressure within the guard cells causes a buckling of the stomata, forcing the epidermal cells out of the way so that the stomate can open.

- Verbal/Social
    - The potato activity, along with the presentation topic of water potential, will spark discussion on the topic of osmosis and water travels through the plant. The topic of water potential is introduced, which will spark further discussion on how water is taken from the soil and transported to the photosynthetic tissue. When examining stomata from different species, students will discuss with each other how varying stomata sizes impact how much water is lost through the leaf. This will then spark the discussion of stomata closure due to drought. Some agricultural fields are irrigated in response to known soil water potentials that induce stomata closure. Students will be given data from an agricultural field with soil water potentials and the water potential of stomata closure. Students will have to decide when would be the most effective time to turn on the irrigation system, which would be cost-effective and stop stomata closure so photosynthesis can continue.

Lesson Three

- Visual:
    - The visual approach to lesson three is the design process of the student's hydraulic system. While working in teams of three or four, if there are an even or odd number of students, students will design their own hydraulic system using tubing and tubing connecting pieces. Further, the students will actually get a proxy for the amount of force required to actually pull water from the soil through tension (negative pressure).

- Verbal/Social
    - This is a very interactive project where the students will have to collaborate on what the best design is. Students will then have to defend their design using the information provided in the previous lessons. After each design is tested, students will then have to discuss where the flaws of their design were and what could have been done to mitigate any issues in the design process.

Inquiry and Contextual Learning Approaches

Lesson One

- Lesson one will be tightly connected to fruit production within the agricultural system. This will demonstrate to the young scholars how a flower eventually develops into a fruit, given the right conditions, and how this is controlled in an agricultural setting. Further, lesson one could also involve a farming budget worksheet, but from the perspective of water sources. This lesson could involve whether agricultural fields are irrigated with wetlands, city water, well water, or not irrigated. This worksheet would have a table showing each water source, the cost of maintaining it, and the yield gained during an experiment (Lesson 1 Potential Worksheet). Students would then have to decide which strategy is best. This activity will illustrate some of the decision-making that occurs in the agricultural management environment.

Lesson Two

- Lesson two will be interwoven into water management in agriculture settings. Scholars will first be introduced to how plants manage their own water loss through stomata closure. This will then be followed by a discussion on how there are species-specific water potential values at which plants close their stomates. This information can then be utilized in an agricultural setting for more effective water management strategies. Students could then be paired in teams and given a simple data set showing the timing of stomata closure relative to soil water potential for a variety of species. Students will then have to design a field management strategy and choose specific locations to "plant" their crops, and how they are going to irrigate their field. Further, students will need to discuss when they should turn the irrigation on. Is it more cost-effective to wait late until right before stomates close and then turn on the irrigation for an extended period of time, or are small increments of drip irrigation more cost-effective (Lesson 2 Potential Worksheet)? These are the types of decisions students will have to make.

Lesson Three

- Lesson three is structured around a project-based learning approach, but this lesson first begins with an inquiry perspective of plant hydraulics. Students will have to recall what they have learned from previous lessons and plan their hydraulic network based on what they know about different flow rates from lesson one. Further, the size of the syringe the students decide to use will relate back to lesson two with the tension required for cells to gain turgor. The syringe will represent plant capacitance (K), the amount of water they are able to store.