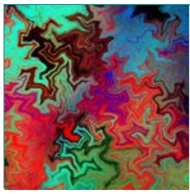

Root Movement

HOW TO USE THIS RESOURCE

The images for this resource, Root Movement and Super Stoma, can serve as anchoring phenomena to explore the key concepts described below. Each image displays a response plants have to stimuli, particularly gravity and water levels, in the case of roots, and water levels and carbon dioxide levels, in the case of stomata.

The pedagogical practice of using phenomena to provide a context for understanding science concepts and topics is an implementation practice supported by the Next Generation Science Standards (NGSS). Phenomena are observable occurrences that students can use to generate science questions for further investigation or to design solutions to problems that drive learning. In this way, phenomena connect learning with what is happening in the world while providing students with the opportunity to apply knowledge while they are building it.

The “Implementation Suggestions” and “Teacher Tips” sections provide options for incorporating the images into a curriculum or unit of study, and can be modified to use as a standalone activity or to supplement an existing lesson. The student handout includes reproductions of the images and the “background information” section.

KEY CONCEPTS

A. Plants, like animals, respond to stimuli in their environments, including light and water levels, temperature, and gravity.
B. Plant responses include feedback mechanisms that maintain plants’ internal conditions within certain limits. These feedback mechanisms can be investigated through experiments.

NGSS PERFORMANCE EXPECTATIONS

HS-LS1-3: Plan and conduct an investigation to provide evidence that feedback mechanisms maintain homeostasis. [Clarification Statement: Examples of investigations could include heart rate response to exercise, stomate response to moisture and temperature, and root development in response to water levels.]

BACKGROUND INFORMATION

Root Movement

Toward the end of his life, Charles Darwin, assisted by his son, Francis, wrote several books on plants including “The Power of Movement in Plants,” published in 1880. The father-and-son team performed many experiments on plants and observed that they exhibit a range of behaviors previously only attributed to animals—a controversial conclusion at the time. For example, cells near the end of the root tip (pictured in the lower center of the image) use the movement of organelles and the release of hormones to sense gravity, which affects the timing and location of cell division and root elongation. Such processes enable a root to grow down into the soil.

To generate this image, *Arabidopsis thaliana* plants were genetically labeled with a plasma membrane marker (in green) and a nuclear marker (in purple). The root tips were imaged using time-lapse microscopy in a confocal microscope with a vertical specimen stage. Growing root tips were tracked using the custom-built “TipTracker” MATLAB® program that allows the microscope to follow the growing root tip. The selected image shows one-time point of the root movement, but a gif of the time-lapse video is available at https://www.hhmi.org/biointeractive/root-movement.

Super Stoma

Stomata are openings, or pores, on the surfaces of leaves that allow plants to take in carbon dioxide, which they use to form organic molecules in photosynthesis. They consist of two epidermal guard cells that allow the pore between them to open and close. Every time a stoma is open, carbon dioxide enters a leaf and water and oxygen (one of the byproducts of photosynthesis) escape. Plants regulate the opening and closing of stomata to ensure a balance between carbon dioxide intake and water loss. The basic structure of stomata (two guard cells flanking a central pore) has been conserved throughout the 400-million-year history of land plants with some variations. For example, in members of the grass family, which evolved in the late Cretaceous, the guard cells are flanked by two support cells that help fine-tune the regulation of pore opening and closing. Such fine-tuning may have enabled grasses to more easily adapt to changing environments. Scientists are now exploring the effects of such changes by studying the grass *Brachypodium distachyon*, which has stomata with the usual two guard cells (center of the image) in addition to many support cells (surrounding the guard cells). Such studies may have practical applications for producing crops with improved carbon assimilation and water use, which could more easily adapt to rapidly changing climates.

To generate this image, the grass tissue was stained with a fluorescent dye that reveals cell outlines (in magenta) and a fluorescent protein attached to a factor involved with the control of gene expression (in yellow), and imaged using laser scanning confocal microscopy.

IMPLEMENTATION SUGGESTIONS

The following suggestions outline several options for incorporating the images into a unit of study as the anchoring phenomenon:

Engagement, establishing prior knowledge, and providing context:

- Ask students, “What distinguishes plants from animals?” Have students generate a list of characteristics that they ascribe to plants, animals, or both. Suggested student answers may focus on how each obtains energy (autotrophs vs. heterotrophs, etc.) or physical characteristics (“Plants are green and have chloroplasts.”). Many students will also suggest that plants “don’t move” or don’t do so as noticeably as animals do.
- Ask students to examine the root movement image using the prompts “I notice …” or “I wonder …”. Note that the cells’ plasma membranes are labeled with a green marker dye and its nuclei with a purple marker dye. Have students share their observations and questions with one another and then share as a class, noting when observations and questions occur in common.
  - Student observations/questions may include that the roots have “offshoots” (root hairs), that nuclei appear to be clustered at the root tip and root exterior, and comment about the relative size and density of cells in various parts of the roots. Roots grow via a zone of cell division containing meristem tissue protected by a root cap, which can be seen in the cluster of nuclei near the end of the root. Cells then elongate and differentiate, which can be seen in the image as cell density decreases and cell size increases.
- Ask students in what direction they think roots normally grow. Most will say “down,” though some may say “down and to the side” or “where their environment ‘tells’ them to grow.”
  - Show students the gif of the “Root Movement” image and ask them to make observations about the root’s behavior.
  - Ask students to consider which environmental stimuli could affect the direction of plant root growth. Student answers may include light levels, gravity, water levels, contact with the soil/growing medium, etc. Have students work in pairs/groups to generate lists of stimuli. Share as a class, noting when common stimuli occur.
- Have students read the caption associated with “Root Movement,” noting any unfamiliar terms.
  - It may be helpful to clarify that “stem” cells are cells that can generate a variety of cell types and are not cells found in the stem of a plant. It may also be helpful to specify that the suffix “tropism” refers to an organism turning toward a particular stimulus to help students unpack the definition of “gravitropism” or “hydrotropism.”

- Ask students to summarize the paragraph to one another, including how Darwin and his son were able to gather evidence concerning plant behavior.
- Tell students that they will examine another image taken from a different part of a plant. Have students examine the Super Stoma image using the prompts "I notice …" or "I wonder …". Note that the cells' outlines have been stained magenta and a factor controlling gene expression stained yellow. Have students share their observations and questions with one another and then share as a class, noting when observations and questions occur in common.
  - Students may note that the cells differ in relative size, shape, and arrangement from the root image. Students also may wonder about the guard cells in the center of the image, noting the appearance of a small space between them.
- Have students read the associated caption, noting any unfamiliar terms. Ask them to identify the environmental stimuli plants respond to, which include water and carbon dioxide levels.
  - Ask students to summarize the paragraph to one another, including why plants open and close their stomata, and why scientists are interested in studying plant responses.

Exploration, assessment, and extension:

- Exploration/Investigation: Students should be able to articulate how (via experiment) and why (crop improvement, among other reasons) scientists study plant responses. Student exploration should include designing their own experiments to study plant responses, such as roots' responses to light, gravity, water, etc., or stomata responses to light, water, or carbon dioxide levels.
- Assessment: Students may be able to articulate that plants need to respond to having too few or too many of a certain resource or stimulus, but struggle to articulate the concept of feedback and/or homeostasis. Have students create initial models (sketches or diagrams) of their plants' predicted responses to their chosen stimuli in the experiment above and then revise these models to illustrate their experimental results.
  - While the NGSS specifies an assessment boundary that excludes intracellular mechanisms involved in controlling root movement or stomatal response, it may be helpful to have students research how plants sense gravity via statoliths or control stomatal opening and closing via potassium, chloride, and water concentrations, and add these findings to the models
- Extension:
  - The "I Contain Multitudes" video Can a Fungus Save Plants from Global Warming? examines how plants handle heat stress through symbioses with fungi. The video traces the process of understanding plant stress tolerance from the observation of an initial phenomenon, through experimental analysis, and into applications for improving crops.
  - Root tips are often used to study mitosis, since they contain many actively dividing cells. Explore mitotic stages, controls, and the effects of dysregulation with the Eukaryotic Cell Cycle and Cancer Click & Learn.

TEACHING TIPS

- Present students with the image(s) first, before they read the background information.
- Background information may be edited to support student proficiency, course sequence, etc.
- The image(s) may be projected in lieu of handouts.
- Pair or group students to work through one or more of the implementation suggestions.

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