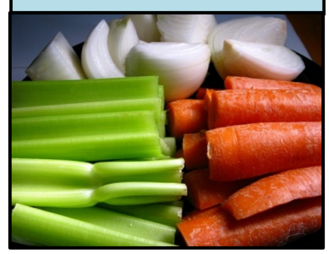
Celery Challenge: **Investigating Water Movement in Plants**	**Student's Guide**



In this module, you will think about ***transpiration***, ***osmosis***, and different ***cell types*** by trying to cause celery stalks to bend as much as possible. Carrying out several experiments while blogging with a plant biologist will help you develop ideas about these processes. Here's what's in store:

- **Become familiar with celery:** You will have opportunities to test the effects of salt solutions on and observe liquid movement through celery stalks. You may observe the cellular structure of celery under a microscope.
- **Laboratory investigation:** You will work in teams to carry out guided observations and use scientific inquiry in developing an experiment testing how much some factor affects celery's bending. During the experiment, you will systematically collect quantitative and qualitative data using observation and measurement skills. You can blog to get feedback about your work from a scientist. In short, you will be doing REAL science!
- **Think like a scientist**: Once you finish the investigations, your team will reason carefully about the results and develop a storyboard communicating your conclusions. You will compare your team's results against those of your classmates. As you look at data from all teams, the class will work together to make sense of it all. You can comment on the work of others, helping achieve the class goal of explaining how different environmental and plant characteristics affect the bending of celery stalks.

Snappy Celery

Isabel's party is tomorrow, and she needs food for twenty. She wants to make appetizers but will also try making several new dishes. When Isabel's friend Mark drops off the punch bowl she is borrowing from him, he suggests that she could make the appetizers this evening to concentrate on the more difficult new dishes tomorrow. Thinking this is a good idea, Isabel decides to include celery sticks to go with her special dipping sauce, a cheese spread, and peanut butter. She remembers her grandmother putting cut celery in glasses of water to keep it fresh, so after cutting the stalks to uniform lengths, Isabel does the same, setting the celery in the refrigerator before going on to other preparations.

What do you think Isabel will find has happened to the celery when she takes it out to put on the vegetable tray tomorrow?

A PlantingScience Resource

Background: Water & Plant Cells

What is the Role of Water in Cells?

Water is the largest component of living cells, often accounting for over 95% of cell mass, and it has many vital roles. Water is the solvent in which most of a cell's molecules are dissolved, and it forms the matrix in which organelles and insoluble molecules are suspended. Many biochemical reactions, including photosynthesis and respiration, include it as one of the reactants or products. Water also transports dissolved materials throughout organisms' bodies. In plant cells, water provides structural support by pressing the cell membrane firmly against the cell wall. A good analogy for this is a bicycle tube and a tire. Like a cell membrane, the rubber tube does not have much strength on its own. However, it can hold its shape when filled with air, and the entire bicycle tire becomes very firm and strong when the filled tube is constricted on the outside by the tire wall. Similarly, cell membranes restrict the movement of water and dissolved substances into and out of the cell, and press against their cell walls when they contain enough water, providing **turgor pressure** to the plant.

What Causes Water Movement Into or Out of Cells?

Diffusion is the movement of molecules from a region of high free energy to a region of lower free energy. Under standard conditions of temperature and pressure, this is simply movement from a region of high concentration to a region of lower concentration. Temperature, pressure, and concentration all affect free energy, so all three factors should be considered if they differ between two different regions. To experience diffusion, have a friend open a bottle of perfume across the room from you. The volatile molecules in the perfume will enter the air, where their concentration is lower, and your friend will soon smell them. As their concentration builds up in the air around your friend, the molecules will travel to where the concentration is lower, eventually reaching your nose.

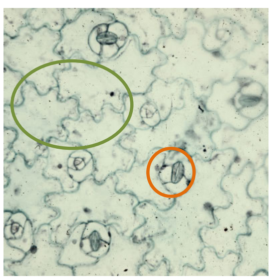
Osmosis is the diffusion of water across a differentially permeable membrane. Cell membranes are differentially permeable, since water passes across them more easily than do most solutes. If a cell is placed in a **hypertonic** solution, one in which the solute concentration is higher than in the cytoplasm, water will diffuse out of the cell, causing **plasmolysis** or cell shriveling. If a plant cell is placed in a **hypotonic** solution, one in which the solute concentration is lower than in the cytoplasm, water will move into the cell. Animal cells may rupture under such conditions. In a plant cell, the additional water creates pressure against the cell wall, and, as described earlier, the cell becomes **turgid**. Solute concentration is the same as in the cell in an **isotonic solution**, and no net movement of water occurs.

How Do Plants Move Water?

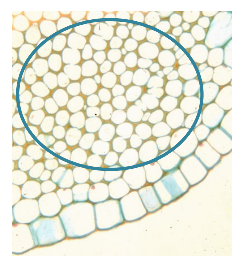
Osmosis drives the transport of water and many solutes between plant cells. While this process occurs at or below the cellular level, plants must move water from their roots all the way to the tallest parts of the plant. For a large tree such as a redwood, that's quite a feat! At the scale of the whole plant, water movement is driven by **transpiration**, the evaporation of water from plant leaves, stems, and flowers. While plant tissues are mostly made up of water, about 90% of the water a plant's roots take up is ultimately lost to transpiration! As water vapor passes from cells to the atmosphere via pores called **stomata** (see below), the relative amount of solutes in those cells increases, making them slightly more hypertonic than the cells more interior to the plant. Osmosis results in the movement of water from the more interior cells to the ones that have lost water, ultimately forming a gradient all the way back to the roots. Due to water's strong surface tension and adhesion to tube walls, some water transport in plants is also accounted for by **capillary action** within the long, tube-like cells of the vascular system.

Do All Plant Cells Use and Transport Water the Same Way?

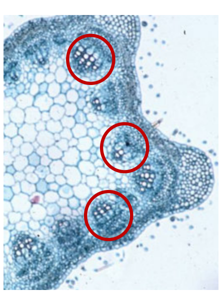
Not all plant cells are identical. For example, celery stalks, or **petioles**, contain all three of the basic cell types found in plants: parenchyma, collenchyma, and sclerenchyma. All plant cells are modified from one of these types. **Parenchyma** are the least specialized cells. They have relatively thin walls made mainly of cellulose, and their main function is to store food and water. Their large central vacuoles press the cytoplasm against their cell walls, often making the cells appear empty. Parenchyma retain the ability to divide even when mature, so they are found in **meristem** tissues where new growth occurs. Parenchyma containing chloroplasts are called **chlorenchyma** and can carry out photosynthesis.



Some parenchyma cells can secrete various chemicals; for example, specialized parenchyma cells called **epidermis** form a protective layer over the surface of plant organs. The side of the epidermal cells facing the external environment is often coated with a waxy layer called the **cuticle**. The epidermis also contains **stomata**, or pores through which gases and water can pass for photosynthesis, respiration, and transpiration. Stomata are each bordered by two **guard cells**, which control the pore size of the stomata by filling with varying amounts of water, depending on environmental conditions.



The next major cell type, **collenchyma**, is found mainly in herbaceous plants or in the herbaceous stage of young, woody tissues. This is a strengthening cell found directly under the epidermis. Collenchyma are elongated cells with unevenly thickened cellulose primary walls. They are often especially thick at the junctions where the walls of multiple cells meet. These cells can also divide when mature.



Sclerenchyma cell walls contain cellulose as well as lignin, a polymer that makes the walls very hard and stiff. These cells are dead at maturity, and their main functions are to protect more delicate cells and to strengthen the plant. Two kinds of sclerenchyma exist: fibers and sclereids. **Fibers** are elongated cells with evenly thick secondary walls; they are usually pointed at the ends. Wood is sclerenchyma typically containing many fibers. Special fiber cells join end to end, forming hollow vascular tubes called **xylem**. Xylem is the main transport cell for water and dissolved minerals from the soil. Like fibers, **sclereids** also have thick walls, but these cells are not elongated or pointed at the ends. They may be branched, resembling stars, or they may be non-branched and referred to as stone cells. Hard seed coats are composed of densely packed sclereids.

Guided Inquiry 1: Party Preparations

How Does Salt Affect Celery Bending?

Edible celery (*Apium graveolens* var. *dulce*) is a plant with a very short stem bearing whorls of compound leaves. Each leaf has a very fleshy, elongated petiole connecting it to the stem, and this petiole is the part of the plant that we eat as celery sticks. As you read about Isabel and her party preparations, you probably imagined that the celery sticks she put into water were bent or curved when she took them out of the refrigerator the next day. The overall goal of the **Celery Challenge** is to explain this bending by carrying out several experiments on celery petioles. The first two experiments should give you some clues about factors that can influence celery bending, helping you come up with your own approach to obtain *maximum* bending and explain why your approach works so well.

In this first **guided investigation**, you will test the effect of salt water on celery bending. You'll prepare celery sticks just like Isabel did and observe how they respond when placed in different solutions. By observing the celery's anatomical and physiological responses, you can begin to understand one factor in petiole bending.

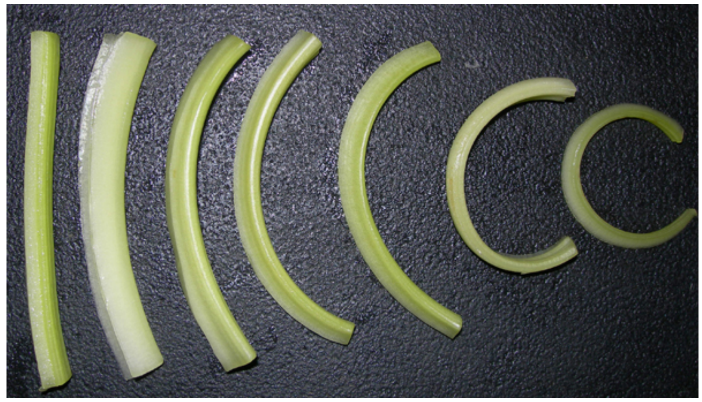
Part I: Setting Up the Celery

1. Obtain three containers tall enough to immerse celery sticks. Cups or beakers work well for this.
2. Prepare two different 100 mL solutions of table salt in tap water. For instance, you could make a 5% and a 10% solution of salt from the grocery store or a 1.0 **M** and a 0.7 **M** solution of lab NaCl.
3. Label the three containers, one as "water" and the other two with the two concentrations of salt you have used. Also label the containers with your team name.
4. Fill one container with tap water and the other two with the salt solutions, as labeled.
5. **Being careful to avoid cutting yourselves**, each person in your team should use a single-edge razor blade or paring knife to cut a celery stalk from the bunch and remove its leaves. The final segment should be 10-15 cm long. Split this lengthwise into three segments about equally wide.
6. Measure the mass, length, width, and thickness of each celery stick and record the data in your lab notebook.
7. Qualitatively describe the appearance and texture of the stick in a sentence or two in your lab notebook.
8. If you have a digital camera available, take a photo of your celery sticks with a metric ruler alongside them for scale. Otherwise, make some sketches in your lab notebook as close to scale as possible.
9. Each member of your team should place one of their celery sticks into each solution container, so that each person has added one replicate to each treatment. Keep track of which stick went in which container in your lab notebook.

10. If a refrigerator is available, place your three containers inside overnight. If not, place them together and record the conditions in your lab notebook. If possible, a cool, dark place is best.
11. Combine your data with that of your teammates so that you can calculate the average dimensions for celery sticks in each treatment. You may also wish to calculate the standard deviation or standard error of the mean for each set to determine how variable your data are.

Part II: Party Time!

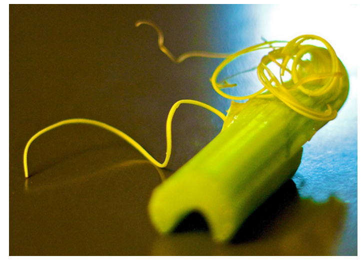
1. The next time your class meets, remove the containers from the refrigerator or their storage place.
2. Qualitatively describe in your lab notebook, as completely as possible, the shape and texture of the celery sticks from each treatment.



3. If you have a digital camera available, take a photo of the celery sticks from each treatment with a metric ruler alongside them for scale. Otherwise, make some sketches in your lab notebook as previously described.
4. Measure the mass, length, width, and thickness of the celery sticks.
5. Calculate the average measurements for each treatment and, if desired, the standard deviation or standard error of the mean for each. Compare this data with that collected during the previous class.
6. Using graphs and written descriptions, summarize the effects of the treatments in your lab notebook:
    - Which treatment produced the most bending? The least?
    - Was there any difficulty in determining which treatment produced the most bending? If so, describe why.
    - Did any other measurements clearly differ between treatments? Note these as well.
7. In your lab notebook, write down **at least five questions** related to changes you have observed. At least **one** question should relate to *qualitative* data and at least **one** to your *quantitative* data.

Guided Inquiry 2: Celery Sucks!

How Does Water Move Through Celery?



The phrase "celery sucks" poses an interesting possibility – if it's literally true, then the celery stalk that you are testing must be alive! In this second **guided investigation**, you will observe whether and how a solution moves through a celery stalk. With the new knowledge from this and the previous experiment, you will soon be ready to develop your own experiment to bend celery stalks!

Part I: Simple Solutions

1. To prepare a tracking solution, fill a container with 2-4 cm of water and add 1-3 drops of red or blue food coloring to it.
    - Green or yellow food coloring should not be used, since it's difficult to tell the difference between the food coloring and the color of the celery.
    - The main goal is to get a deeply colored solution, so approximate measurements are OK!
2. Break off a single stalk of fresh celery from the bunch and, **taking care not to cut yourself**, use a single-edge razor blade or paring knife to make a clean cut across the base of the petiole.
3. Set the celery stalk into the tracking solution and support it so that it will stand upright overnight. One possible approach is shown at right.
4. In your lab notebook, describe the appearance and texture of your celery stalk and the conditions where it will stand until your next class session.

Part II: What Has Transpired?

1. The next time your class meets, remove the containers from their storage place.
2. Examine the celery stalk carefully – both the cut bottom surface and the overall appearance of the stalk. Describe and make sketches in your lab notebook to illustrate the locations where food coloring is concentrated.
3. Briefly summarize your findings in your lab notebook. Do your observations support the idea that the celery stalk is alive? What other conclusions can you draw from your observations?
4. In your lab notebook, write down **at least five questions** related to where the food coloring was originally located and its distribution in the celery stalk after the incubation period.

Open Inquiry: The Celery Challenge

How and Why Can We Get the Most Bending?

In this **open investigation**, your team will develop an experiment to try bending celery stalks to the greatest extent possible. Based on what you have learned in the previous investigations, you can select similar factors to test or new ones that you think may be related to what you have already observed. After you have tried to obtain maximum bending, you will try to explain why you observed what you did in this experiment and compare your results with those of other teams. Ultimately, the entire class will develop a working model of how celery bending happens based on everyone's findings across all investigations.

Part I. Formulate a Research Question and Research Prediction

1. As a team, choose one of the questions you asked after making your observations in **Party Preparations** or **Celery Sucks!**
    - Can the question be tested using an experiment? If not, select a different question.
2. Consider how the *research question* your team has chosen relates to the challenge of causing celery stalks to bend and how it might help explain why this occurs.
3. Work as a team to think about what you believe the answer to your research question might be.
    - It's okay not to know the answer! Scientists may have some idea about an answer, but they carry out experiments to find out for sure.
    - As a start, try to describe what your think the result would be if you treated the celery in a certain way.
        - For example, "If we place celery in 15% salt water, the celery will bend more than if we place it in 5% salt water" is a concrete way of thinking about how to answer the question "Do higher salt concentrations cause greater bending in celery stalks?"
    - A full research prediction also includes a statement of why you think the outcome will be as your suggest. Work as a team to come up with this explanation.
4. Record your thinking in the **Experimental Design** worksheet. **Share your ideas with your mentor.**

Part II. Design an Experiment

1. Considering the scenario your team developed in the "if-then" statement, discuss how to build the scenario into a full experiment with control and experimental treatments.
    - Account for what you have already learned. For example, you don't need to repeat a salt concentration you've tried if you think another concentration will get more bending.

2. Your team should ask itself:
    - Which *independent variable(s)* will we change, and what will *the dependent variable(s)* be?

- What *qualitative* and *quantitative* data will we record?
    - Do colors, tissue types, or cell types matter?
    - How will we measure celery bending?
    - What kinds of tables or graphs do we want to create at the end of the experiment?
- Are there considerations specific to celery, osmosis, transpiration, cell type, or tissue type?
    - For example, if a solution is so weak or so strong that it kills celery cells, how might that affect bending?
- How many celery stalks will we need?
    - To calculate averages (including average percentages) or statistics, include at least three replicates per treatment.
    - To calculate individual percentages, ten items yields one replicate.
- Most importantly, **does our experiment address our research question?**
    - Ask this several times as you go, and change your experiment if you get off track.

3. Some specific experimental methods are available in the **PlantingScience Celery Challenge Toolkit**. If one or more of the methods listed at right might help your team test your research question, ask your teacher if it can be used.
4. As you go, fill out the **Experimental Design** worksheet to help describe your *research plan*.

PlantingScience Celery Challenge Toolkit

- **Quantifying Water Mass of Plants**
- **Identifying Celery Tissue and Cell Types**
- **Determining the Osmolarity of a Solution**
- **Cutting Transverse Sections of Plant Tissues for Microscopy**
- **Plant Cell Staining Techniques**
- **Visualizing Plant Cells Using a Microscope**
- **Visualizing and Counting Stomata Using the Leaf Impression Method**
- **Making Epidermal Peels for Microscopy**
- **Measuring Transpiration Using a Simple Potometer**

Part III. Get Feedback to Improve Your Experiment

1. Use your team blog to talk with your scientist mentor about what biological processes are involved in celery bending. Feel free to ask questions!
2. Blog about your research question, research prediction, and experimental design.
3. Your mentor, and perhaps your classmates, will give feedback on your ideas and plans. Scientists regularly do this, because collaboration makes science stronger!
4. Adjust your ideas and plans based on feedback if you think it will improve the outcome.
5. Record all changes in your team blog and the **Experimental Design** worksheet.

Part IV. Plan Ahead!

1. As a team, carefully review your experimental design, including the measurements you plan to take. Picturing each step in your minds, ask yourselves:
    - What materials do we need for this step?
        - Let your teacher know everything you plan to use and how much of each item you need.
    - Are we all comfortable doing this step?

        - If not, every team member should practice it **at least once** before the experiment. It's okay to take a full class period to practice if it means you will collect accurate data later!
    - Must this step happen quickly or in a certain time period?
        - If so, work as a team to figure out how each member can play a role in ensuring the step is carried out properly and in the right time frame.
2. Next, prepare data collection materials:
    - At which steps will you record data? How often, and in what format? Who will record it?
    - What are the units for each type of data?
    - Is a written journal enough? Will you need a computer spreadsheet during or after the experiment?
    - What format will allow you to record the data most easily?
        - A sample data collection sheet is shown here, but it is not suited for all experiments:

Data Form for Team: ________________________ Member of Team: ______________________
Number of total stalks: __________________ Experimental conditions: _____________________

Treatment	Length (cm)	Width (mm)	Thickness (mm)	Amount of bending	Qualitative Data (e.g., color, sponginess)

3. Finally, consider the experiment as a whole:
    - Which steps will be happening each day?
    - Are there ways to streamline the procedures?
    - Who will do each part of the work to ensure that all data is collected and everyone helps?

Part V: Carry Out the Experiment

- Carry out the methods you looked over and practiced in **Part IV**.
- Each team member should keep a research journal, if you have not done so earlier.
    - Record all your work that someone else would need to do to recreate your experiment.
    - Record quantitative and qualitative data. Feel free to include sketches!
    - If you see something during the experiment that makes you question your earlier ideas, you may record new observations, thoughts, and ideas. This is a great source of new discoveries and experiments!
    - Record any human errors that happen as the experiment is carried out.
- Keep in touch with your scientist mentor! S/He may be able to provide feedback if you have new ideas or your have trouble.
- If you have time, you can even do a follow-up experiment based on any new observations.


Removing xylem from a celery stalk

Part VI: Analyze Your Data

- Decide which observations and data you need to analyze.
  - Data with no clear patterns might be left out of your final presentation if it does not strongly support or refute your prediction.
- Put your data into a format that others can easily read and compare.
  - Tables or graphs may be appropriate depending on the type of *raw data*, or measurements and qualitative notes, you have recorded in your journal.
  - Summarizing your data can help you see trends and patterns more easily.
  - It is not always possible to see differences in the dependent variables between treatments in an experiment, but stating that you found no difference is ok when this happens!

Part VII: Make Sense of What Happened

- With your teammates, reflect on every part of the investigation, considering the results carefully. Some key questions to ask include:
  - Did the experiment work, or did something prevent us from taking reliable data?
  - What is the best evidence we collected that helps answer the research question?
  - Does our data support or contradict our prediction?
  - Based on our evidence, what is the best explanation of what is happening?
  - How did we arrive at this explanation? Are other explanations possible?
  - Are there remaining or new questions that arose? If so, what experiment could we do next?
- The **Making Sense of the Data** worksheet can help your team develop a well-reasoned, convincing argument to explain how you know whether the experiment worked and what the results mean.
- You will have to share your findings in a Storyboard Discussion, so be able to explain what you write. You may also have to prepare a final poster, presentation, or report.
- Share your team's ideas with your scientist mentor to practice and get feedback on your ideas!
- Your teacher will lead the Storyboard Discussion, during which each team will explain its findings to the class.
  - Ask for feedback and to provide feedback on your peers' work. Scientists do this regularly by giving presentations and submitting articles for peer review before publishing them.
  - If your ideas change after you receive feedback and see others' findings, it's perfectly fine to revise your thinking. Every scientist has been wrong many, many times in his/her career. The challenge is finding out how things really work!
  - At the end of the Storyboard Discussion, the class will identify which treatments produced the most celery bending overall and develop a model to describe all known factors contributing to this bending.