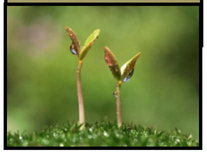
# The Wonder of Seeds:
# Investigations in Germination & Plant Growth

**Student's Guide**



In this module, you will join a team to think about ***germination*** and ***plant growth*** by carrying out an experiment to help answer a research question. You'll create a blog where you'll post your ideas and share your data with a plant biologist. Your team will discuss what you learned with your classmates. Here's what's in store:

- **Get re-acquainted with plants:** You will have opportunities to generate ideas about how plants germinate and grow, learn about seeds, document the early part of the plant life cycle, and discover how to care for seedlings. You might compare seed morphology, dispersal, and growth across species.
- **Laboratory investigation**: You will work in teams, using scientific inquiry in developing a plan to test a research question. During the experiment, you will collect and graph data, using observation and measurement skills. You can blog to get feedback about your experiment from a scientist. In short, you will be doing REAL science!
- **Think like a scientist:** Once you finish the investigation, your team will reason carefully about the outcome to develop a storyboard communicating your findings. 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 germination and growth.

## *Crime-Solving Seeds*

***The blue plaid blanket was the only witness to the crime.*** After four days of searching, police found the suspect's car. In the trunk was a blanket, damp and covered in crushed leaves and other plant material. Detective Wright arrested the suspect and immediately called a forensic botanist to examine the evidence. "Interesting," said Dr. Green, "it is unusual to see beard grass, dog fennel, and beak rush growing together." Pointing to seeds embedded in the blanket fibers, she said, "Look, a few are starting to germinate." She took the blanket to the lab for further analysis, later collecting plant samples from the crime scene and around town. At the trial, the suspect claimed he had never been near the crime scene, saying the blanket got dirty during a picnic at the city park the day before his arrest. Called to the witness stand to provide expert testimony, Dr. Green confidently noted that the seeds on the blanket were species that never grow at the park!

As you can see from Dr. Green's work, humans use seeds in ways that are sometimes surprising! Seeds are important to us as food and to grow crops, but they also represent a critical part of the plant life cycle. Their presence can provide information about the environment in which they are found. In this investigation, you will look at how plants begin their lives as seeds and grow over time. You'll also be asking questions about how the environment might affect germination and growth – why some plants can succeed in habitats where others cannot.

# *Background:* Seed Germination and Plant Growth

### *What is a seed?*

A seed is a ripened *ovule* of a fertilized flower. All seeds contain a diploid *embryo* and a food supply. Most have a protective outer *seed coat* that encloses the embryonic root or *radicle*, the *hypocotyl* or embryonic stem, and one or more seed leaves called *cotyledons*. The number of cotyledons differs based on the plant species. In *gymnosperms* such as pines or ginkgoes, the number of cotyledons is variable. *Angiosperms*, or flowering plants, may contain one cotyledon, as found in *monocots* like oats, tulips, and onions, or two cotyledons. Plants of the latter type are informally called *dicots*, but this group actually consists of *eudicots* ("true dicots") such as beans and sunflowers, as well as *basal angiosperms* like magnolias and water lilies. Dicot seeds store their energy reserves in their cotyledons. Monocots store their energy reserves, which are usually high in starch, in a separate *endosperm*. Certain monocots, like corn or wheat, have their seed coats fused to part of the ovary wall to form structures called *grains* or *cereals*.

Seed variation can be dramatic. The smallest seeds, from plants in the orchid family, are as small as dust particles, while the world's largest, the double coconut in the palm family, weighs up to 40 pounds. Seeds also vary in their mode of *dispersal*, that is, how they are spread from a parent plant into the environment. Maple seeds have a wing-like shape and can be carried by winds. Many seeds are found on the surface of or buried deep inside fruits like strawberries or blueberries. Animals that eat these fruits disperse the seeds in their feces, contributing nutrients to the seed's new environment. Cockleburs have hooks to "hitch a ride" on fur or clothing, eventually getting pulled off elsewhere.

### *How Does Germination Work?*

After dispersal, seeds remain inactive, or *dormant*, until environmental conditions are favorable for germination and growth. Sometimes this phase can continue for quite a long time. Seeds might get eaten or infested with harmful microbes, eventually killing them, but even old seeds might germinate when the conditions are right. Would you be surprised if a seed germinated after 200 years of dormancy? What about after 2,000 years? 32,000? Scientists have germinated seeds of all three ages!

The first step in germination, *imbibition*, occurs when a dry seed absorbs water and begins to swell. Water softens the seed coat, allowing moisture to seep into the seed more deeply. Water then activates enzymes in the embryo, and it becomes metabolically active, using its stored food supply to fuel early growth. The root sprouts first, pushing out of the softened seed coat and growing downward as it responds to gravity. The stem and cotyledons then sprout, growing toward the sun and shedding the seed coat. As cells in the root and shoot tips, or *apical meristems*, divide and differentiate, the stem elongates and the roots grow deeper in a process called *primary growth*.

### *What Helps Seedlings Grow?*

As a seedling's shoot reaches sunlight, it begins to photosynthesize, allowing it to continue growing once the seedling's stored food is used up. If not enough sunlight is available for a seedling to produce its own food, it may die once its reserves are used up.

Different plant species are adapted to different *habitats*. Think of the great variety of environments where plants are found: mountains, deserts, woodlands, lakes, and rain forests. A plant's genetic makeup influences when it reproduces, germinates, and grows, and how it responds to external factors like temperature, moisture, and light. The environmental conditions favorable for one plant species are not necessarily favorable for others. Similarly, different kinds of seeds respond in different ways to a given environmental factor and can remain dormant for different periods.

Gardeners often modify the environment for the seeds and plants they are growing to provide them with the best possible environment for that species. For example, the photo at left shows plants growing in a cold frame. Light can enter the box through the clear, glass walls, but when spring, fall, or (in southern climates) winter temperatures are cold enough to harm the plants, the lid can be closed to help trap heat from the sunlight. When the temperatures are warm again, a gardener can leave the lid open or remove the plants from the box and place them outside.

# How Might a Seed's Environment Influence its Germination and Growth?

In this investigation, you will examine how a seed's germination and subsequent growth are influenced by environmental variables using scientific inquiry. Scientific inquiry is a special case of inquiry that relies on understanding basic concepts to ask a testable research question. Testing a question in an experiment provides data to help scientists understand whether their ideas based on their background knowledge about a biological process are accurate. In an ideal situation, the result of an experiment generates new knowledge and new questions, regardless of whether or not a scientist's initial ideas were accurate. Scientific inquiry is a cycle that never ends – one good question leads to many more!

### *Is my inquiry guided or open?*

In a **guided** inquiry, your teacher will assign a research question to the entire class. Each team will come up with a way to test that question by designing an experiment. In an **open** inquiry, your class will discuss some broad questions, but your team will brainstorm and choose its own research question before designing the experiment. For the open inquiry, begin with *Step 1A*. Both inquiry types are the same for *Step 1B* and beyond.

### *Step 1A. (**OPEN**) Brainstorm a Research Question.*

Inquiry begins by looking carefully around you and wondering about what you see. Once you see something interesting, you naturally want to find out more about it. At this point in the inquiry cycle, all questions are good questions! What do you want to investigate -- the beauty and biology of variation, the fun of physiology, the effect of environment?

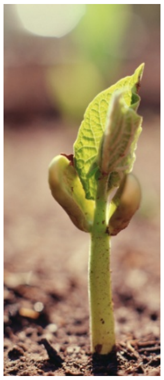
Use the **Student Roadmap through an Investigation's** "Research Question" to help you and your team come up with your own research question. The main requirements are that your question must be (a) testable using one or more investigations and (b) related to **germination** or **seedling growth**. Your teacher might ask you to focus *only* on one of the biological processes. The **Brainstorming Page** worksheet is a handy way to get your ideas down on paper. To finalize a question you select for study, talk your ideas over with your mentor, and perhaps share your **About Our Research Question** worksheet.

Selecting a question that can be answered through investigation gets easier with experience. *Why* questions are really difficult to answer, but *how*, *what*, *when*, and *where* kinds of questions are more testable. Some testable questions past **PlantingScience** teams have asked about **germination** and **plant growth** are:

- **What is the effect of fire on seed germination?**
- **Does the color of clover seed affect the seeds' germination success?**
- **How does soil salinity impact seed germination?**
- **Will seedlings grow better under sunlight or under a lamp?**
- **How does gravity affect plant growth?**
- **How does plant growth medium (e.g., soil, hydroponics, sand) affect seedling growth?**

## *Step 1B. Understand the research question and what it means to test it.*

Spend a few minutes considering what your research question means. For example, suppose your class will be studying the question: **Do monocots and eudicots germinate at different rates?**



First, it may help to focus on the *tricky or vague* parts of the question. In this case, what is meant by "germinate"? What happens during germination? Does it look different for monocots and eudicots? Second, what does "rate" mean – is it the percentage of seeds that germinate or the amount of time each seed needs to germinate? Answering such questions will help later, in *Step 2*.

Next, your team can also describe its *background knowledge*. Do you know many examples of monocots and eudicots? If so, where did that knowledge come from? If not, you should spend some time learning which plants fit into each category. What trustworthy sources of information can help?

Finally, come up with ideas about *what is happening* in the biological process. Why do you think the two types of seeds may germinate at different rates, or at the same rate? You may wish to develop a *working model* of the biological process in the question. Completing the **About Our Research Question** worksheet can help you clarify your thinking.

## *Step 2. Design your experiment.*

The goal here is to decide on the best approach for testing your research question. Use the **Student Roadmap through an Investigation's** "Planning your Study" for guidelines, and fill out the **Experimental Design** worksheet to keep track of your team's *experimental design*. Along with the worksheet(s) from *Step 1*, this will be part of your *research plan*. Your team should ask itself:

- Which *independent variable(s)* will we change, and which conditions will we keep constant?
- What are we going to observe, measure, or count – what will the *dependent variable(s)* be?
    - Will we record *qualitative* data, such as seed color or texture?
    - Will we record *quantitative* data, such as root length or percentage of seeds that germinate?
    - What kinds of tables or graphs do we want to create at the end of the experiment?
- Are there considerations specific to the biological process we plan to test?
    - For example, what are possible benchmarks for germination? Which one is the best for our goals?

    - To draw meaningful conclusions, it is important to record information on multiple individuals.
        - If you will calculate averages or statistics, include at least five seeds per treatment.
        - If you will calculate percent germination, include at least ten seeds to yield one calculation.
        - To calculate *average* percent germination, at least three replicates are needed per treatment.
        - Few plant species have 100% germination success, even under ideal conditions. You may wish to plant extra seeds for any measurements where germination must occur before you can collect data.
- 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.

Creativity is valued among scientists. Breakthroughs often come when a researcher looks at a problem in a new way or tries a novel method to answer a question. Figuring out your own way of providing a light treatment to seedlings, for example, could let you test a question that is otherwise unanswerable. Equally important is careful and systematic thinking, planning, and measuring. If you will test the effect of light intensity on plant growth, for example, keeping conditions like temperature and moisture the same for all plants is critical.

## *Step 3. Predict what will happen in your experiment.*

The **Student Roadmap through an Investigation's** "Research Question" describes what a *research prediction* is and how to develop one. Record your thinking in the **Experimental Design** worksheet. As a basic guide, ask yourselves:

- What do we predict will happen if we conduct the test and our ideas are correct?
- What do we think is happening biologically that makes our answers credible?

## *Step 4. Blog your ideas.*

Science does not occur in a vacuum. Scientists often work in teams and collaborate with other research labs to answer the same question, or to connect their experiments with others to help answer bigger questions.

- Talk with your scientist about your ideas on how a seed's environment might affect germination and growth.
- Get feedback on your research plan, and if needed, make changes to it before starting the experiment(s).

## *Step 5. Practice and plan ahead!*

As a team, carefully run through your experimental design, including the methods described on pp. 10-13. Picturing each step in your minds, ask yourselves:

- What materials do we need for this step? Are they in the Materials list? (If not, let your teacher know.)
- Are we all comfortable doing this step? (If not, everyone should practice it **at least once** before the experiment.)
- Must this step happen quickly or in a certain time period? How will we ensure it occurs as needed?

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 for the data during or after the experiment?
- What sort of 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** _______________________
**Seed species** ___________________________________ **Number of seeds** __________________
**Seed description:**
**Experimental conditions:**

| **Date** | **Length (cm)** | **Width (cm)** | **Seed(ling) number** | **Seed swells; seed coat cracks; roots, shoots, leaves visible?** | **Other Observations** |
|---|---|---|---|---|---|
| | | | | | |
| | | | | | |

Finally, consider the experiment as a whole:

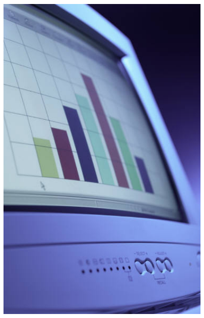
- In general, which steps will be happening each day?
- Are there ways to streamline the procedures?
- Who will do each part of the work to ensure that all data is collected and seed(ling)s are cared for?

### *Step 6. Carry out your experiment(s).*

Besides carrying out the methods you have looked over and practiced in *Step 5*, each member of your team will need to keep a research journal. This is a place to record data and jot down new thoughts or ideas, creating a long-term record of your work. As you carry out the experiment, record everything someone would need to know to recreate it themselves. Record, photograph, illustrate, or graph your data as needed. Even if it wasn't put into the experimental design, take special care to record anything you observe that you think might influence any part of your data, and note any human errors. For further tips, see the Keeping a Research Journal page on the **PlantingScience** website.

The class will have about two weeks to work on experiments, so explore and perfect your protocols if needed. Your scientist mentor may be able to provide feedback if you have trouble or new ideas. For example, you might notice something early on that could be important in figuring out what your data mean, such as seed size or which seeds germinate fastest. You may be able to add this new observation even after you start, make regular measurements of it, and include it in your results. This kind of careful observation can be a great source of new experiments and discoveries! If you find interesting results leading to a new question and you have time, you can even do a follow-up experiment.

## *Step 7. Visualize and analyze your data.*



Your data is the "evidence" you will interpret and use as a basis for drawing conclusions. The numbers and notes in your journal are called *raw data*. This needs to be put into a format that others can easily read and compare. Which observations and data do you need to analyze, and how can you best display them to others? Summarizing the data in tables, graphs, or charts will help you see trends and patterns in your observations and help you make sense of it. Information on the **PlantingScience** website can help you learn about Making Meaningful Graphs and, if you want to use software, Using a Spreadsheet. See the **Student Roadmap through an Investigation**'s "Visualizing and Analyzing Data" for other tips about analyzing your data.

It is not always possible to see differences in the dependent variables between the treatments a research group selects, but stating that you found no difference is okay! A good analysis can open up more questions that might lead to new experiments, and a result of no difference may provide clear avenues towards a new experiment.

## *Step 8. Make sense of what happened.*

With your teammates, reflect on every part of the investigation, considering the results carefully. See the **Student Roadmap through an Investigation**'s "Making Sense of Findings" for tips on developing explanations about what you observed. 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?

Filling out the **Making Sense of the Data** worksheet can help with the process of developing a well-reasoned, convincing argument to explain how you know whether the experiment worked and what the overall 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. You can share your team's ideas with your scientist mentor to practice!

Your teacher will lead the Storyboard Discussion, during which your team will explain its findings to your classmates. Be sure to ask for feedback and to provide feedback on your peers' work. Scientists do this regularly by giving presentations at meetings 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. That's how science keeps moving forward. Every scientist has been wrong many, many times in their career. The challenge is finding out how things really work!

***Happy sprout farming!***

## *CONSTRUCTING A GROWTH CHAMBER TO MONITOR SEED GERMINATION OR PLANT GROWTH*

**Purpose**: Create a suitable environment for seed germination and plant growth.

**How the Method Works:** Plant seeds are in a dormant state and must be provided with a favorable environment before they will germinate. Such environments are usually also suitable for plant growth. This method involves planting seeds so that they can be observed as they germinate and grow. As an alternative to placing seeds in soil, this approach allows monitoring of the earliest stages of germination, when the root and cotyledons first break the seed coat.

**Technical Skill:** Simple.

**Time Required**: About 20 minutes per day for two days for chamber construction and seed preparation, and 5 minutes per day thereafter for seedling care (excluding any measurements).

---

### Materials:

- Plant seeds for at least two treatment groups
- Container for soaking seeds, at least 4 cm deep
- Water
- Petri dishes, sealable plastic bags, or empty soda bottles
- Paper towels
- Scissors
- Permanent marker
- (*Method C*) Washed sand
- (*Method D*) Rubber band and netting or cheesecloth
- Light source (40W or higher)
- Ruler
- String
- (*Optional*) Magnifying lens
- (*Optional*) Digital camera
- Means to monitor or control environmental conditions, such as:
    - Thermometer and heater/cooler
    - Colored lights or light filters
    - Light timers
    - Table salt
    - Fertilizer
    - Acid or base solution and pH meter or measuring strips

### Safety Notes:

Wear gloves, goggles, and a lab coat when handling chemicals. Lights can be hot, and UV lamps can damage eyesight. Seeds may be treated with irritating chemicals like fungicides or cause allergic reactions. Do not eat or drink in the lab!

### *Part 1: Seed Preparation (~10 minutes)*

2. Choose the kind of seed you will study.
3. List the seed you will be growing, conditions to be tested, team name, and your name in your research journal.
    - Do you have enough seeds for all treatments? Each treatment should use the same number of seeds.
4. Count out the number of seeds you will use and enter the number in your research journal.
5. Examine the seeds you will be using. Record your observations, measurements, sketches, and other notes in your research journal, especially if you see clear variations within the group.
    - (*Optional*) A hand lens may help you make better observations of small seeds.
    - (*Optional*) A digital camera can help you document any interesting patterns you see.
6. (*Optional*) Look at other teams' seeds, taking notes on size, coloring, and shape to get an idea of seed diversity.
7. Place your seeds in a container, and cover them with 2-3 cm of water.
8. Soak the seeds overnight to soften the seed coat and let seeds imbibe water, starting the germination process.

### *Part 2: Build Growth Chambers (~10 minutes)*

1. Once the seeds are soaking, choose which type of growth chamber to make from the four methods below.
    - The best choice depends mainly on how many seeds you will study.
2. Figure out how many growth chambers to make.
    - You will need at least one chamber for each treatment.
    - If you will measure percent germination, each replicate should have its own chamber.
3. Gather the materials you need to build the correct number of chambers.
4. With a permanent marker, label the outside of each chamber with the planned treatment, type of seeds, planting date, and your team name.
5. Construct the chambers according the method you selected.

#### <u>*Method A: Petri Dish*</u>

1. Fold a paper towel so that it forms 3-4 layers.
2. Place the folded paper towel into a Petri dish. Trim with scissors as needed to fit the dish.
    - The size is usually sufficient to fit 3-8 seeds in one dish.
3. If available, you can cover the open dish with a clear plastic or glass lid to limit moisture loss later.

*Method B: Bagged Seeds*

1. Fold a paper towel so that it forms 2-3 layers.
2. Check the size of the folded paper towel to ensure that it will fit flat in a sealable plastic bag. Trim as needed.
3. In pencil, mark out spaces for the seeds in one treatment/replicate, so that the seeds will be aligned in a row.
    - The size is usually sufficient to fit 6-12 seeds in one bag.
4. Place the paper towel inside the bag.

*Method C: Bottle's Edge*

1. Clean a clear plastic drink container and cut off the top half.
2. Line the bottom half of the container with a paper towel folded to form 2-3 layers.
    - The towel should run up the sides of the container. Cut small wedges from the towel if this helps it fit.
    - In pencil, mark out spaces for each seed, so that they will be aligned evenly in a circle.
    - You should be able to fit 10-30 seeds, depending on the size of the bottle.
3. Place clean sand in the bottom to keep the paper towel in place.

*Method D: Bottle's Base*

1. Clean a clear plastic container having a basically flat or rounded bottom and cut off the top half.
    - You will be able to fit anywhere from ¼ teaspoon to 1 tablespoon of seeds, depending on the size of the bottle. This will cover the container bottom with one layer of seeds.
2. Cover the top with netting or cheesecloth secured by a rubber band.

### ***Part 3. Plant the Seeds (~20 minutes)***

1. After seeds have soaked overnight, pour out the water and blot the seeds on a paper towel.
    - Seeds that are too wet will rot instead of germinating, so they should not sit in water from this point on.
2. Examine your seeds; record observations and any measurements, especially if you see changes.
3. Place the soaked seeds in their growth chambers.
    - Seeds should be distributed so that any that are clearly different from the group overall are equally abundant across treatments and replicates, not all placed in the same group.
    - For *Methods A and B*, open the chamber, moisten the paper towel with water, then place the seeds in their marked locations. Close the chamber.
    - For *Method C*, pour a small amount of water onto the sand, then place seeds in their marked locations between the sidewall of the bottle and the paper towel.
        - The water will wick up the paper towel to provide moisture to the seeds.
    - For *Method D*, remove the netting, place seeds on the bottom of the container in a single layer, and replace the netting.
    - If your experiment involves treatment with different liquids, use these instead of water as needed.

4. Place growth chambers in their test conditions.
    - If you don't have enough space in your classroom, you can take your growth chamber(s) home. Be sure to discuss with your team how the different conditions in your homes might affect the experiment.

### *Part 4. Growing the Seedlings (~5 minutes per day)*

Over the experimental period, you will need to keep the germinating seeds or seedlings moist in addition to taking any planned measurements. Check the growth chambers daily to be sure everything is in good shape, returning each growth chamber to its test location after observation and care is complete for the day.

- For *Methods A-C*, you will probably need to moisten the paper towel about two or three times each week.
- For *Method D*, you will need to rinse the seeds or seedlings every day or two.
    - Gently run water into the growth chamber through the netting and gently swish the seeds in the water.
    - Pour the water out through the netting and gently shake the chamber to remove excess water.
    - It is helpful to let the seeds drain upside down for a minute or so to avoid pooling water.