

Laboratory: Environment and Development: The Effects of Environment on Seed Germination

The seed is more than just a plant waiting to happen. It is a complex marvel of evolution, a miniature life-support system that responds to environmental cues in order to give the embryo nestled within the best chance of survival.

I. Characteristics and Classification of Plants

Plants share synapomorphies that set them apart from other organisms.

1. true tissues (of types unique to plants)
2. waxy cuticle (to prevent desiccation)
3. stomates (microscopic gas exchange pores on the leaves)
4. apical meristems (permanent embryonic tissue for constant growth)
5. multicellular sex organs (male **antheridia** and female **archegonia**)
6. walled **spores** produced in structures called **sporangia**
7. embryo development inside the female parent
8. secondary metabolites (alkaloids, tannins, flavonoids, etc.)
9. heteromorphic **alternation of generations**

The most primitive plants do not produce seeds at all, but rather release **spores** into the environment where they grow into a second life cycle stage, called the **gametophyte**. In seed plants, the life cycle is highly derived. Seed plants still make spores, but each spore grows into a gametophyte that is little more than a bit of tissue that gives rise to gametes. In the male parts of the plant, each spore develops into a sperm-producing male gametophyte known as **pollen**. In the female parts of the plant, meiosis occurs inside a structure known as the **ovule**, which will eventually give rise to the **seed**.

Plants can broadly be classified as follows.

- A. Bryophytes – non-vascular plants (mosses, liverworts and hornworts)
- B. Tracheophytes – vascular Plants
 1. seedless vascular plants (ferns, club "mosses", horsetails, etc.)
 2. seed-producing plants
 - a. gymnosperms (cycads, ginkos, conifers)
 - b. angiosperms (flowering plants)

Today, we will use seeds of flowering plants (angiosperms) as our study organisms.

II. The Plant Life Cycle in a Nutshell

Most familiar plants are **vascular** plants: they have conducting tissues to transport water and nutrients throughout the body of the plant. **Xylem** transports water and dissolved minerals from the roots to the rest of the plant. **Phloem** transports dissolved organic substances throughout the plant, in multiple directions.

When we think of plant reproduction, we usually think “seed.” But not all plants produce seeds. The earliest vascular plants, such as ferns, undergo meiosis to produce haploid structures called **spores**. It is only the more recently evolved seed plants that produce the complex, protective capsule known as a **seed**.

All plants undergo the same basic life cycle, which is surprisingly different from the animal life cycle. In plants, there are two main life cycle stages, the **sporophyte (diploid)** and the **gametophyte (haploid)**. These are separate, individual plants, though the vascular plant gametophyte is so highly derived (little more than a blob of tissue) that you may never see one and recognize it. The plants you see outside the window are sporophytes.

A. Alternation of Generations

Repeat after me:

1. The offspring of diploid sporophytes are haploid gametophytes.
2. The offspring of haploid gametophytes are diploid sporophytes.
3. This continuous, back-and forth changing of ploidy between parent and offspring generations is known as **alternation of generations**, and is shown in Figure GR-1.

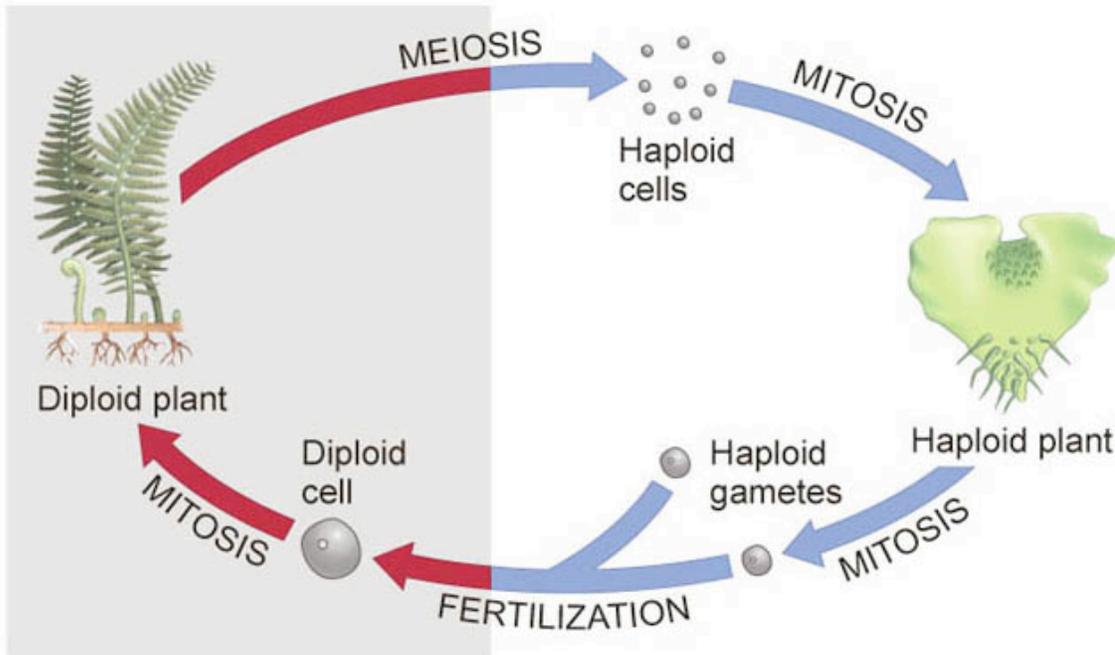


Figure GR-1. Alternation of generations, as exemplified by a fern plant. The cycle is the same in all vascular plants, although sporophyte (diploid) and gametophyte (haploid) are very different in appearance in the same species.

Recall that ferns do not produce seeds. They simply release their spores into the environment, where they can grow into gametophytes.

The seed plant life cycle is more derived. To produce male gametophytes, seed plants produce diploid germ cells inside **microsporangia**. These undergo meiosis to produce **microspores**. Each microspore develops into a **microgametophyte**, a **pollen** grain, which produces two **sperm**. The pollen is a streamlined gamete-generating structure, and lacks even the antheridia of more primitive plants.

Think it couldn't get any worse? Sit yourself down to hear about the female.

In seed plants, female gametes are produced inside a structure known as an **ovule**. This consists of three layers: the integuments (which will become the seed coat), the **megasporangium** (within which diploid cells are undergoing meiosis), and the **megagametophyte** (the haploid product of those diploid, meiotic cells). The megagametophyte produces **ova** (eggs) via mitosis.

In pines and other gymnosperm ("naked seed") plants, the **megagametophyte** still produces ova within an archegonium. But in the highly derived flowering plants (also known as anthophytes), even the archegonia are lost. Instead, each megaspore develops into megagametophyte (female) that is simply a mass of cytoplasm containing eight, mitotically produced haploid nuclei. Only one of these will become the **ovum**. (Figure GR-2)

Once the ovum is fertilized, the ovule has technically become a **seed**. It develops into a protective, nutrient-rich capsule that will protect the new sporophyte generation until it germinates.

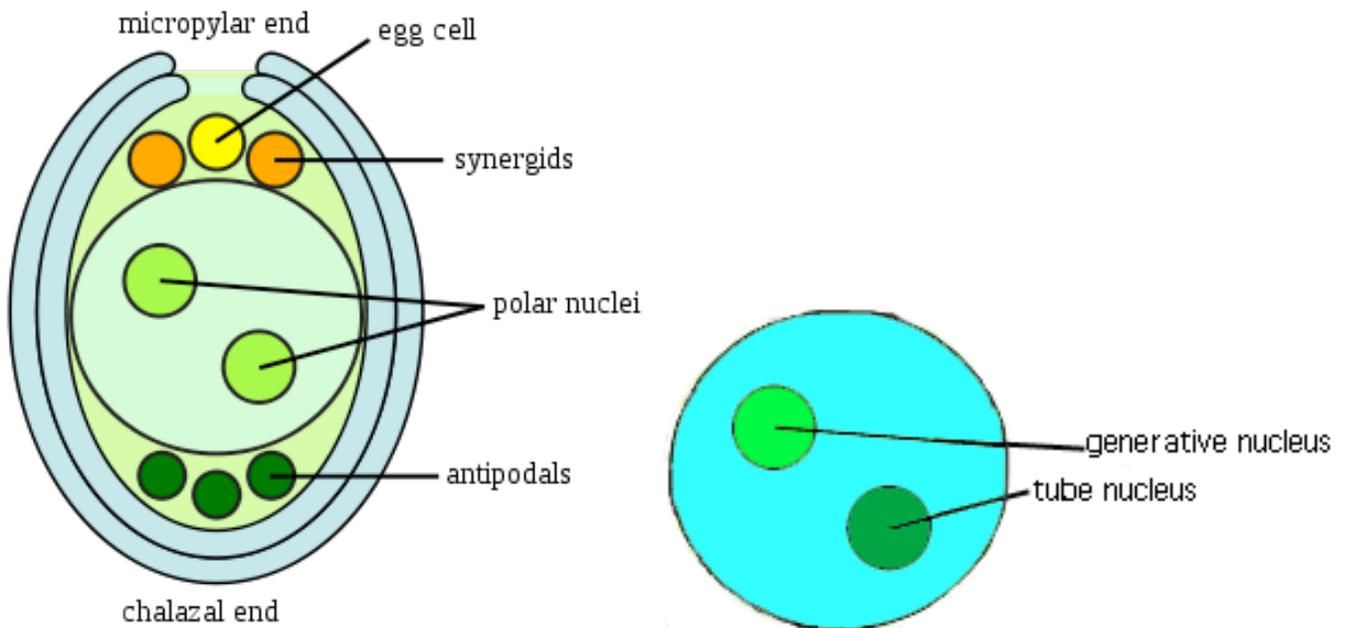


Figure GR-2. The megagametophyte (left, female) and microgametophyte (right, male) of a flowering plant. The ovum (egg cell) is bordered by two synergids. The binucleate pollen mitotically generates two sperm from the generative nucleus. One of the sperm will fuse with the ovum to become the zygote (sporophyte embryo). The other will fuse with the two polar nuclei to form triploid ($3n$) endosperm that will nourish the embryo as it develops and germinates. (photo courtesy of <http://www.thefullwiki.org/Ovule>)

B. Anatomy of a Seed

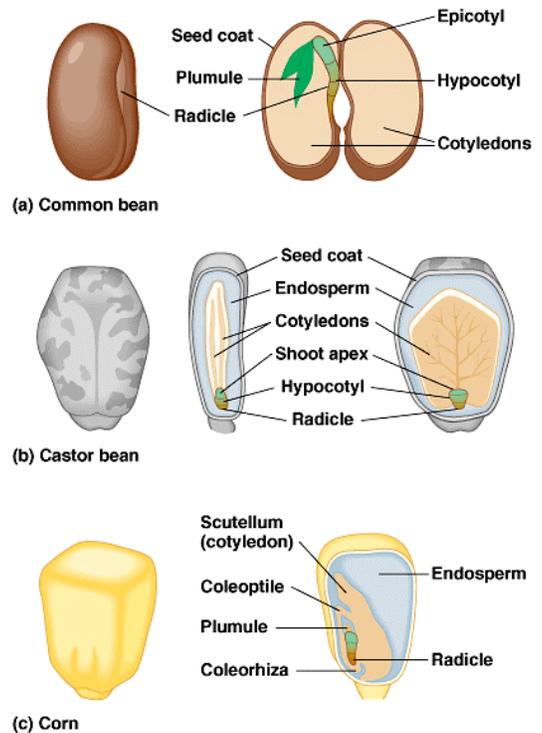
A seed is composed of the tissues of three generations of plants:

- (1) the sporophyte that produced the seed (an immature seed is called an **ovule**),
- (2) the gametophyte that develops inside the ovule and produces ova, and
- (3) the new sporophyte embryo.

The seed also contains a nutritive substance, **endosperm**, upon which the growing embryo feeds as it develops. The anatomy of some typical angiosperm seeds is shown in Figure GR-3.

Seed characteristics vary with plant species, and have evolved different anatomies in response to natural selection and other evolutionary forces. For example, seeds of plants that grow into **epiphytes** (i.e., plants that grow on other plants, such as bromeliads, orchids, etc.) tend to be very small and easy for wind to carry to high places. They have comparatively little endosperm so as to reduce weight, and so have relatively little reserve energy to produce a sprout during germination.

Conversely, seeds of species that germinate deep underground (e.g., beans, corn, etc.) may have extensive reserves of endosperm, as the deeper a seed is buried, the more energy it must spend to grow a sprout that can break the surface to reach sunlight and make its own food via photosynthesis.



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Figure GR-3. The anatomy of three different species of flowering plant seeds. Cotyledons are the first embryonic leaves. The radicle is the embryonic root.

C. Dormancy and Germination

Dormancy can be defined as the physiological condition of a viable seed that prevents germination. During dormancy, the seed's metabolic rate is extremely slow, and it uses very little energy to stay alive.

Germination is the reactivation of metabolic activity in the seed, an awakening from dormancy. It culminates with the emergence of the **radicle** (embryonic root) and finally, the **plumule** (first shoot). Germination can be divided into three main phases:

Phase I – Activation

This phase commences with **imbibition**, the uptake of water by the seed. This causes the seed to increase in volume. Respiration increases, and various enzymes involved in endosperm digestion and other functions are manufactured. The cells of the embryo begin to elongate, and the radicle begins to grow.

Phase II – Digestion and Translocation

During this phase, metabolic activity increases dramatically. Protein synthesis begins, and endosperm is metabolized. Enzymes soften and loosen the cell walls, in preparation for further cell elongation and volume increase. Nutrients from the endosperm (sometimes located in the cotyledons) are mobilized and transported to areas of growth.

Phase III – Seedling Growth

This phase is characterized by rapid cell elongation and cell division. At this point, the radicle emerges from the seed coat, and the embryo can now access water and nutrients from its environment for the first time. The new plant begins its journey.

III. Factors Affecting Seed Germination

As mentioned previously, many seeds undergo a period of **dormancy**, during which metabolic activity is minimal. In part, dormancy can be maintained by a hormone, **abscisic acid** (ABA), which permeates the seed coat. In order for germination to commence, this water-soluble ABA must be rinsed out of the seed coat. Hence, most seeds will not begin to germinate until they have been rinsed or soaked in water.

Changes in oxygen, light, temperature, soil chemistry, and/or humidity each may play a role in triggering germination. The effect of any environmental stimulus on a seed depends on its own unique genes as determined by the evolutionary history of its ancestors and any new mutations it may carry.

Does it matter to a seed when and where it germinates? Can a seed's failure to detect environmental conditions result in a lower chance of survival, and its being dumped out of the gene pool? What environmental factors influence seed germination success, and how? In today's lab, your team will consider these questions, as well as others of your own invention.

As you already know, there may be genetic variation not only among *different* species, but also among individuals of the *same* species. Don't forget this when you design your experiment. Following is a bit of background on some environmental factors that could affect dormancy and germination in various flowering plant species. Consider not only these factors, but also the anatomy and natural history of the species provided for you in the lab. Since multiple factors may affect germination, you must be aware of them all to properly interpret your experimental results.

A. After-ripening

Some seeds will not germinate until they have undergone a process of **after-ripening**, defined as metabolic changes that must take place in a seed in order for it to overcome dormancy. For example, the seeds of some temperate species will not germinate until after they have been exposed to very cold temperatures. Other seeds must pass through an animal's digestive tract and become **scarified** (physically damaged) before they can take up water and become metabolically active. Still others must pass through fire, which is common in ecosystems where annual fires are part of the normal climate. Of what ecological and evolutionary significance might each of these after-ripening triggers be?

Cold - _____

Animal Digestive Tract Passage _____

Fire - _____

B. Light Environment

A **pigment** is a substance that absorbs and reflects light in a characteristic fashion. In living systems, organic pigments can trigger biological reactions. Plants have a variety of pigments that function in capacities other than photosynthesis.

Even the seeds of some plant species may have special photosensitive pigments that "tell" the seed whether it is close to sunlight or not. Short-wavelength light (e.g., violet and blue) penetrates deeper into soil (and other substrates, such as water) than long-wavelength light (red). To which wavelengths of light would you expect such seed pigments to be sensitive, short or long, and why?

Sensitivity to light keeps seed from germinating where they can't grow, such as under a canopy where there is not enough light, or if they have been buried too deeply in the soil. To detect light, any organism must have some sort of **pigment**, a light-absorbing substance. In this case, it must be a pigment that can trigger a biological reaction.

Phytochromes

Phytochromes are proteinaceous molecules with a sulfur-linked (covalently bonded) pigment active group (the chromophore) consisting of a linear tetrapyrrole. The pigment absorbs primarily in the red and far-red region of the spectrum, and so appears blue-green to our eyes. The chromophore portion of the molecule can exist in one of two forms, Pr or Pfr, as shown in Figure GR-4.

The functional phytochrome consists of two identical proteins, each with a chromophore. One part of the protein acts as the photoreceptor, and the other as a kinase, which triggers cellular responses. When the chromophore absorbs light, it isomerizes from one form to the other. This change in configuration results in a slight change in the kinase portion of the protein. The kinase is the biologically active region of the molecule, and its interaction with other biological molecules elicits a physiological response.

The more stable isomer is Pr, but it is not biologically active. In the presence of even a short flash of red light, this molecule isomerizes to the biologically active form, Pfr, which can trigger various metabolic responses in a plant, from blooming to inhibition of blooming to germination, depending on the activity of the kinase portion of the molecule. In darkness, or in the presence of far red light, Pfr returns to the more stable form, Pr. Given this information, consider what types of seeds might use phytochromes as receptors to relay information about light environment. Might there be a difference in light sensitivity among different species of seeds? Might different wavelengths (colors) of light have different effects on germination? Ask questions and make predictions.

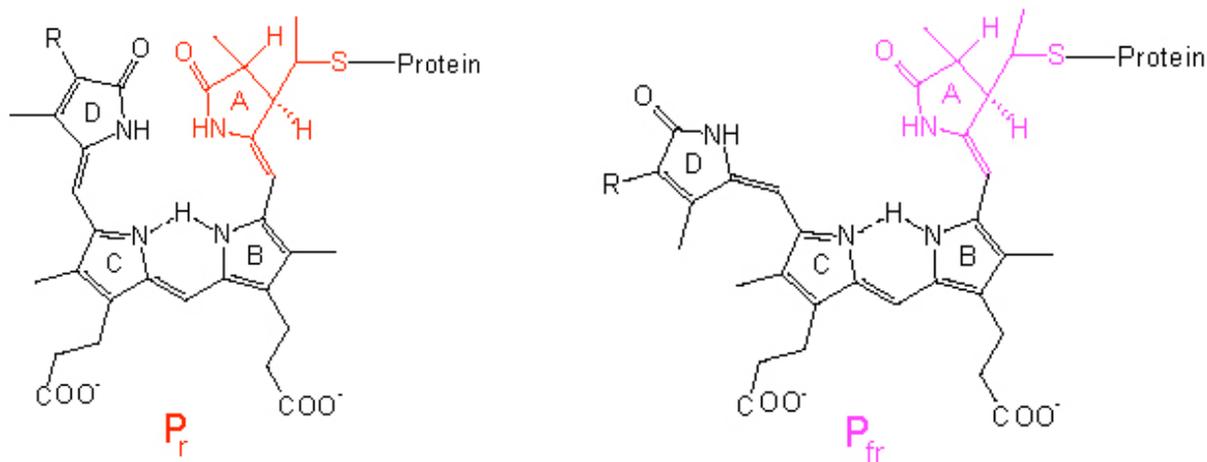


Figure GR-4. Phytochrome red (Pr, on the left) and Phytochrome far-red (Pfr) are isomers. In the presence of red light (~680nm), Pr isomerizes to the biologically active form, Pfr. In darkness or when exposed to far red light (~700nm or longer), Pfr changes back to the more stable isomer, Pr.

C. Temperature Environment

Different plants have different responses to temperature depending on their evolutionary history and where they have evolved. **Cool temperature tolerant** plants are found primarily in temperate regions (between 30° – 60° latitude, north and south). Optimum temperature for growth ranges between 77° - 86°F, although various species can tolerate a range of 40° - 104°F. Cool temperature tolerant species include domestic cultivars of *Brassica oleracea*, such as broccoli, cabbage, turnips, cauliflower, etc. as well as many temperate grasses.

Cool temperature requiring species require temperatures lower than 77°F. Seeds from these species will generally not germinate if temperatures are too warm, but require after-ripening triggered by a period of very cold temperatures (40° F or lower). Examples include lilacs, freesias, apples.

Warm temperature requiring plants tend to occur in the tropics (between 0° – 23.5° latitude, north and south) and subtropics (between 23.5° – 30° latitude, north and south). These species require temperatures of at least 50° - 60° F in order to germinate. Examples include beans, eggplant, corn, tomatoes, and peppers.

Alternating/Fluctuating day-night temperature plants. Some seeds require a drastic temperature differential in order to break dormancy. Such species as conifers, and wild roses need at least an 18° F (10°C) difference between day and night before they can germinate.

D. Soil Environment

Soil must be of adequate hydration, oxygen levels, proper particle size, and tolerable chemical environment in order for seeds in the soil to germinate. Depth of planting can have marked effects on seed germination success, as oxygen and light decrease with soil depth. Soil particle size can also affect these factors: the smaller the soil particle size, the less passage of light there will be through the soil.

Acidity or alkalinity of soil can affect germination success or germination rate. Soil that is hypertonic also can inhibit germination, as high osmotic potential in the seed's environment will prevent water from moving into the seed. Too much fertilizer can thus inhibit seed germination, as can living in a very dry environment, such as a desert.

Soil water must be present in the appropriate amount. Too little water will prevent proper metabolism, whereas too much can literally drown the seeds, which die of anoxia (lack of oxygen).

You can probably think of other variables of soil condition that might affect germination rate or germination success. Consider every possible option before you decide on the question your team will answer.

E. Competition, Secondary Metabolites and Allelopathy

When resources are limited, and there is competition for them between members of the same species (**intraspecific** competition) or different species (**interspecific** competition), might the density of individuals in the system play a role in germination success? By what mechanism? Faster germination time? Or perhaps even via inhibition of the germination and/or growth of other individuals or species?

Competition for light, space, and nutrients in the plant world can be ferocious. But how do you fight when you're (literally) rooted to the spot? As you might already have guessed, plants are the greatest purveyors of chemical warfare.

Metabolites are compounds made via metabolic reactions. **Primary metabolites** are those found in all cells, and are necessary for normal cellular function and energy transduction. These include things like biological macromolecules (nucleic acids, proteins, lipids, carbohydrates) and simple sugars.

Secondary metabolites are complex chemical compounds that are NOT found in every cell, and not found in every species of plant. Once thought to be waste products of metabolism, they are now known to serve many vital plant functions, such as

- * analogs to animal neurotransmitters (albeit a lot slower)
- * natural antibiotics or anti-fungals
- * deterrents against herbivores
- * allelopathy
- * attracting pollinators
- * attracting seed dispersers
- * protecting young plant parts from harmful UV radiation

Like animal hormones, plant secondary metabolites are usually produced in a specific location of the plant, and then transported for storage (usually in vacuoles) to another part of the plant. Production of the compounds often follows a Circadian rhythm, with concentration varying in a diurnal cycle, seasonally, or even with environmental influence, depending on the plant producing it and the specific compound being produced. The three major types of plant secondary metabolites are **alkaloids**, **terpenoids**, and **phenolics**.

Allelopathy is defined as the inhibition of growth in one species of plants by chemicals produced by another species. This is one important function of plant certain secondary metabolites. It's more common to find plants with allelopathic compounds in areas where evolution has driven fierce competition for space and resources. Plants that have evolved in geologically old biomes (where there has been ample time for mutation and natural selection to operate), and in the tropics (where growth, reproduction, diversity and abundance of species are at their maximum) are the most common players in this plant drama.

Florida is relatively young, geologically speaking. Native plant species here have not been evolving and competing nearly as long as those in areas such as the Amazon Basin, Australian forests, or African habitats. So when species from those localities are imported here (accidentally or on purpose) and then escape cultivation, there can be disastrous consequences, especially if the escaped species are allelopathic.

Three such examples form a cohort of Public Enemy Number One, One, and One in southern Florida: the **Australian Pine** (*Casuarina equisetifolia*), the **Cajeput** or **Paperbark Tree** (*Melaleuca leucadendra*), and the **Brazilian Pepper** (*Schinus terebinthifolius*). Wherever these species are introduced into native Florida ecosystems, they tend to out-compete native species. They simply take over, creating vast stands of a single species (a **monoculture**) and severely restricting food and shelter for native wildlife. How do these **invasive exotic** plants do it? Might allelopathy be playing a role?

IV. Experimental Design

Now that you have read and considered some of the factors that can affect seed germination, it's time to put your knowledge to work. Before you don your thinking caps, read the following section on setting up your Germination Chambers so you will have an idea of how your replicates will be assembled, and know their advantages and limitations.

A. Materials

Various supplies have been provided that you can use to design and execute your experiment. It is wise to check to see what is available, and then meet with your team to decide on a hypothesis, a prediction, and an experimental protocol.

These basic supplies will be available, but you may use others of your own, if you wish.

1. Lettuce seeds
2. Petri dishes
(Each group should take no more than 6 petri dishes, half for treatment and half for control. You can, of course, place more than one seed per dish.)
3. filter paper to fit the Petri dishes
4. Tape and wax pencil markers to label your experimental vessels
7. light sources
8. various colors of cellophane to act as light filters
9. compound stereoscopes
10. blenders
11. distilled water
12. beakers, graduated cylinders, and other glassware

B. Methods

Before you begin, read this section to familiarize yourself with the basic set up of the germination chambers. This will help you design an experiment that will work within our space and resource constraints.

Many environmental variables may affect germination when lettuce seeds experience them singly, in combination, or in sequence. Check out the back counter of the lab to see what is available for you to use. You may go outside to collect leaves, leaf litter, pond/lake water, or other relevant materials to manipulate your seeds' environment. Think about what these various conditions might tell the seed about the suitability of the present (or future) environment for growth, and then, with your team, come up with a problem to solve. Develop a rationale for your team's project, and then design an experiment. You may use up to 12 mini-germination chambers (a.k.a., petri dishes) per group.

1. Hormones regulate seed dormancy, and in most seeds the hormones are in the tissues of the seed—not in the seed coat. The exception is some seeds of desert plants, which must be able to germinate immediately when substantial (and perhaps unpredictable) rainfall occurs. Abscisic acid (ABA) in the seed coat washes off, releasing the seed from dormancy (Koenig 1994). Lettuce seeds evolved in temperate, rainy climates, where rain is not a sufficient cue for good growing conditions—so there is no external ABA, and you don't have to rinse the seeds.
2. Place one 9 cm filter paper circle in the *bottom* half (not the lid) of each Petri dish. The paper is a little too big to fit exactly, so use a glass rod to nestle it as flat as possible in the dish bottom.
3. Place 50 dry seeds in each of your dishes, (unless your hypothesis involves the effect of seed density on germination).
4. Add 5 mL of water (or your own group's manipulated solution) per dish, to moisten your dry seeds and begin the imbibing process. Seeds are sensitive to environmental cues only after imbibition (Finch-Savage and Leubner-Metzger 2006). (If you are using the thicker filter paper made from solvent saturation pads, use 7cc of water or solution per dish.)
5. Seeds begin to sense their light environment within minutes after they imbibe water. Therefore, apply any light treatments (using foil, cellophane, or wrapped lettuce leaf filters)

immediately after moistening the seeds, or they may begin to respond to the ambient light, rather than to your intended treatment. For the same reason, do not remove the light treatments, once applied, for even an instant—unless that is part of the intended treatment.

6. You may be asking, “If I can’t remove the foil or cellophane (or lettuce leaf), how will I record my germination data?” Good question! We have set up a special darkroom with filtered light (out of the sensitivity range of phytochromes), for you to safely look at your seeds over the course of your experiment. The darkroom is located in Cox 110, under the hood at the back of the room.
7. Cover the petri dish with the lid and tack it shut with masking tape. DO NOT seal the dish! The seeds need oxygen to survive, and you don't want to suffocate them.
8. Label each dish appropriately with masking tape and wax pencil. Make sure your team’s name is on the label.
9. Place your petri dishes on the germination shelves in the lab, and note their location. This will be your team’s spot for the duration of the experiment. Label it appropriately.
10. Petri dishes are translucent. You may not need to open the dishes to check on your sample unless you need special protection from light and are working in the darkroom. Use the dissection scopes in the lab to help magnify your samples to get a better look at them for accurate data collection.

If you think you can put any materials from outside in the arboretum or native biome to good use, then go for it! Be creative and questing.

C. Consider the System, Pose a Problem to Solve

Plant species occur on almost every continent, and the species of plants in any given ecosystem often define what type of animals and other organisms can survive there. In each species, natural selection has resulted in evolution of seeds that germinate when conditions are most favorable for growth in that species’ particular environment, and which remain dormant when conditions would not be favorable.

Domesticated crops, however, have been artificially selected to germinate reliably when the farmer decides to plant them (or else he or she might not plant that variety again). Thus, many domesticated crops whose wild ancestors once had seed dormancy have lost it.

A case in point is lettuce (*Lactuca sativa*). The wild ancestors of lettuce were probably weedy colonizers of disturbed areas in temperate Eurasia. In a forest, the seeds that did best would lie dormant in the soil until a light gap opened above them. Buried seeds that were able to delay germination until the soil was disturbed, bringing buried seeds to the surface, also may have had a selective advantage. In addition, germination had to be timed so that the young plants could complete most of their growth in the cool, rainy weather of spring, not in the fall (when frost might kill a young plant) or in the summer (when it might be too hot and dry for optimal growth). Ancestral wild lettuce thus evolved a combination of light- and temperature-mediated seed dormancy.

Classic studies demonstrating that dormancy could be regulated by red and far-red light were performed using one of the last varieties of modern lettuce to retain ancestral seed dormancy, *Lactuca sativa* ‘Grand Rapids’ (Borthwick et al. 1954). Since then, under relentless selection for “uniform germination,” most strains of Grand Rapids no longer show seed dormancy. However, one variety, Waldmann’s Dark Green, still does (Neff et al. 2009). And we have searched far and wide to obtain this variety for your experimenting pleasure!

In **teams of four**, discuss what you now know about seeds germination and the factors affecting this process. Consider the following list of variables (and suggestions for how to manipulate them), or choose your own.

Light variables:

Ambient light

Darkness

Cellophane light filters: red, blue, yellow, green

Far red light filters, made in two possible ways:

-red + blue cellophane (Takaki and Zaia 1984)

-lettuce leaves in plastic wrap (Neff et al. 2009)

Temperature variables:

Room temperature

Outside temperatures

Refrigeration at 4°C for one to several days (Margaris and Fiaku 1974, VanDerWoude and Toole 1980)

Freezing at below 0°C for one to several days

Heat shock at 30°C for 15-30 min (Takaki and Zaia 1984)

Nutrient and soil variables:

Inorganic fertilizer solutions (manufacturer's recommended maximum concentration = 0.12%)

0.05 M phosphate buffers, pH 6.0 – 8.0

NaCl solutions (as a starting point, the salinity of seawater is about 3%)

Brackish water from Lake Osceola

Fresh water from the microbiome pond

Organic compost "tea"

South Florida limestone soil "tea"

Slash pine needle litter tea from the remnant pine rockland (potentially allelopathic)

Brazilian pepper leaf litter tea from the remnant pine rockland (potentially allelopathic)

Mixed species leaf litter tea from the hardwood hammock microbiome

Other variables:

Seed density

D. Hypotheses and Predictions

When contemplating your experimental design, consider what your treatments will be (including controls, if needed), and what your *experimental unit* (a.k.a., *unit of replication*) is. Different designs may suggest different controls. Possible designs using 12 dishes include 2 treatments with 6 replicates each, or 3 treatments with 4 replicates each. As in real life, there are tradeoffs in experimental design: more treatments (therefore with fewer replicates of each) means you can ask more complicated and interesting questions, while more replicates (of fewer treatments) means you may have a better chance of actually answering your question—by finding out whether the results of your treatments were statistically significant. It's the adventure of science—choose your design wisely, execute it carefully, and enjoy!

Following are a few guidelines that will help you.

1. Pose your hypotheses and make predictions based on all possible outcomes of your experiment.
2. Choose the parameter of germination you will use to gauge experimental effect. Here are a few suggestions, but feel free to choose something relevant that's not on this list.
 - a. time to emergence of radicle (this will happen first, but might require a stereoscope to see)
 - b. time to emergence of plummule
 - c. number of seeds successfully germinated over specific, selected time intervals

Hypothesis 2: _____

Prediction: _____

Outcome 1: _____

Outcome 2: _____

Outcome 3: _____

How frequently will you record data? _____

What environmental conditions will you record and keep constant in your system? _____

What factor will you vary, and how? _____

Which statistical test will you use to analyze your data? _____

When all teams have a good idea of the hypotheses they want to test, and the experimental design they'll use, your TA will allow each team about five minutes to explain its idea to the class for critique and revision.

Before you leave lab today, your team should devise an appropriate data collection sheet, properly labeled, so that you will have a template ready to go when you begin to record your data. Use any software you deem appropriate, if only to create a grid for your raw data.

Be sure to use appropriate units of measure, indicate the time/day of your recording, and every bit of information that might be relevant when it comes time to analyze your results and put them together into a Power Point presentation for your lab colleagues to watch and critique. The Seed Germination Symposium will take place after spring break. Refer to the online syllabus for specific dates.

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The Kindergarten Wall

*Of all you learn here, remember this the best:
Don't hurt each other and clean up your mess.
Take a nap every day, wash before you eat,
Hold hands, stick together,
Look before you cross the street.
And remember the seed in the little paper cup:
First the root goes down,
and then the plant grows up!*

--John McCutcheon