Plant Growth: Germinating Seeds

SC Academic Standards: 4.L.5A; 5.L.4A; 6.L.5B; 7.L.3A; 7.EC.5A-B; H.B.3A; H.B.2D; H.B.6A-D

NGSS DCI: 4-LS1.A; 5-LS1.C; 5-LS2.A; 5-ESS3.C; MS-LS1-C; MS-PS3.D; MS-LS2.A; MS-LS2.C; HS-LS1.B-C; HS-LS2 A-C

Science and Engineering Practices: S.1A.1; S.1A.2; S.1A.3; S.1A.4; S.1A.5; S.1A.7; S.1A.8

Crosscutting Concepts: Patterns, Cause and Effect: Mechanism and Explanation; Structure and Function; Energy and Matter: Flows, Cycles, Conservation, and Systems Models, Stability and Change.

Focus Question(s): What factors are important in seed germination? How does planting orientation, seed size, planting depth, and addition of growth hormones affect seed germination?

Background: Flowering plants (and gymnosperms, but not ferns or mosses) come from **seeds**. A seed is a ripened **ovule** of a fertilized flower. All seeds contain a diploid embryo and a food supply, and most have a protective seed coat.

Each seed contains a tiny plant embryo waiting for the right conditions to **germinate**, or start to grow. Seeds wait to germinate until three needs are met: water, correct temperature (warmth), and a good location (such as in soil). During its early stages of growth, the seedling relies upon the food supplies stored with it in the seed until it is large enough for its own leaves to begin making food through photosynthesis – so it doesn't necessarily need the sun right away, though it will eventually. All seeds have a built-in ability to orient themselves correctly and grow according to gravity. The roots will grow toward the pull of gravity and the stem or shoot will grow up and away from it. This is known as **gravitropism**.

Seedling development starts with germination of the seed. A typical young seedling consists of three main parts: the radicle (embryonic root), the hypocotyl (embryonic shoot), and the cotyledons (seed leaves). Monocot Angiosperms have one cotyledon and Dicot Angiosperms have two; Gymnosperms are more varied and may have up to 24 cotyledons! The cotyledons may last only days after emergence, or may endure for longer. The cotyledons contain the stored food reserves of the seed. As these reserves are used up, the cotyledons may turn green and begin photosynthesis, or may wither as the first true leaves take over food production for the seedling.

The seedling's roots start growing first, and push down into the soil to anchor the new plant and to absorb water and minerals from the soil. And its stem, with new leaves, pushes up toward the light. The germination stage ends when a shoot emerges from the soil. But the plant is not done growing. It's just started. Plants need water, warmth, nutrients from the soil, and light to continue to grow. Water is obtained from the soil, through the roots, and contains many dissolved nutrients. Light comes from the sun and is absorbed by chlorophyll in the leaves (and green stems). Oxygen is generally absorbed via the roots from the soil as well, but CO_2 is absorbed (and excess oxygen released) from the leaves, through small pores called stomata.

The radicle, or part of the seed that was attached to the parent plant, is where the root will emerge. If the seed orientation has it pointed down, the new root will grow straight down with no wasted energy. If it is pointed upwards, the root and stem has to change direction, which uses a lot of energy stored in the seed and decreases the vigor. In nature, flat or oblong seeds tend to be deposited in a horizontal position, so the stem and root will only need to change direction by 90° and won't waste a lot of energy.

In this lab we will look at four things: the effects of planting depth, the effects of seed orientation, and the effects of seed size, and addition of growth hormones, on germination of seedlings. Germination begins with water imbibition (uptake) by the seed and ends when the seedling emerges from the soil. So, once you are able to detect seedling growth, germination has finished and the seedling developmental stage has begun.

<u>Materials</u>: Bean seeds, grass seeds, radish seeds (presoaked 24 hours), pots, soil, black cow compost, water, Q-tips, Gibberellic Acid (Amazon.com, $10, Supergrow gibberellic acid starter kit, concentrated).

Make a good garden soil mix by using 50% black cow composted cow manure (to hold mositre) and 50% garden soil (not potting soil, and try to find some without miracle grow/ fertilizer added).

<u>Previous Knowledge: (botany):</u> Seedling development starts with germination of the seed. A typical young seedling consists of three main parts: the radicle (embryonic root), the hypocotyl (embryonic shoot), and the cotyledons (seed leaves). Monocot Angiosperms have one cotyledon and Dicot Angiosperms have two; Gymnosperms are more varied and may have up to 24 cotyledons! The cotyledons may last only days after emergence, or may endure for longer. The cotyledons contain the stored food reserves of the seed. As these reserves are used up, the cotyledons may turn green and begin photosynthesis, or may wither as the first true leaves take over food production for the seedling.

Both plants and animals produce hormones that can regulate growth. Gibberellins are a group of plant hormones that affect growth. The effects of these hormones were first observed in the 1920s in rice plants that were attacked by a fungus, these rice plants grew unusually tall. Scientists isolated the substance responsible for the growth (*Gibberala fujikuroi*). Gibberellic acid is derived from this chemical and is used to make plants grow taller.

Procedure:

* Pre-soak bean seeds in a cup of water overnight. For each of the three experiments, have each group prepare pots with 5 seeds each – one pot for each treatment. For the hormone experiment, the GA3 powder is not water-soluble and has to be dissolved in a couple drops of rubbing alcohol before mixing with water or it will make a snow globe of clumps that won't dissolve. Two scoops (attached to kit) will make about 1 fl. Oz. of 1000 ppm. There are also a lot of teachers that claim soaking the seeds in hydrogen peroxide works just as well (though it isn't a hormone): 1 cup H_2O plus 1.5 tsp H_2O_2; soak overnight – it gives an added O_2 boost and may kill off anaerobic bacteria.

The recommended planting depth for most seeds is generally 1-1/2 to 2 times the width of the seed.

Last, germination rate may be important to take note of too – you don't always get all 5 seeds in a pot to germinate (thus, we plant 5 – replicates – and each group in the class has 5 seeds per treatment, so really, you should have like 30 replicates). But, when calculating average amount of time to germinate, don't average in zeros (for never germinated) - if 4 / 5 seeds germinate, just use the 4 values to calculate the average amount of time to germinate.

Part 1: Seed Size

1. Prepare three pots with soil / compost mixture. Water with 50 ml of water.
2. Plant 5 grass seeds in pot 1; 5 radish seeds in pot 2; 5 bean seeds in pot 3. Each seed should be about 0.5 cm below the surface of the soil when finished planting.
3. Let sit for two weeks. Water every other day with 20-25 ml of water (same amount in each pot, adjust according to your classroom climate).
4. Each day during the two weeks, make a note of which seeds germinated first, and measure the shoot length (in cm) of each seedling. When calculating averages, don't count seeds that don't germinate (don't average in a zero!)
5. Does seed size make a difference as to how fast germination completes (when the shoot first pokes through the soil surface)?
6. Does seed size make a difference as to length of seedling (growth rate)? Growth rate = size / time.

Day	Shoot length																	
	Grass (small; 1 cotyledon)					AVG (mm)	Radish (medium; 2 cotyledons)					AVG (mm)	Bean (large; 2 cotyledons)					AVG (mm)
1																		
2																		
3																		
4																		
5																		
6																		
7																		
8																		
9																		
10																		

Table 1. Average shoot length after two weeks of growth for seedlings from three different sized seeds.

Seed Size	Days to Germination					AVG (days)
	Seed #					
	1	2	3	4	5	
Grass (small, single cotyledon)						
Radish (medium, 2 cotyledons)						
Bean (large, 2 cotyledons)						

Table 2. Days to Germination (day seedling first became visible above soil surface).

Part 2: Seed Planting Depth

1. Prepare three pots with soil/compost mix. Water with 50 ml of water.
2. Plant 5 radish seeds in pot 1, 4 cm beneath the surface.
3. Plant 5 radish seeds in pot 2, 2 cm beneath the surface
4. Plant 5 radish seeds in pot 3, 1 cm before the surface.
5. Let sit for two weeks. Water every other day with 20-25 ml of water (same amount in each pot).

6. Each day during the two weeks, make a note of which seeds germinated first. When calculating averages, don't count seeds that don't germinate (don't average in a zero!)
7. Does depth of planting make a difference as to how fast germination completes (when the shoot first pokes through the soil surface)?

Seed Size	**Days to Germination**					**AVG (days)**
	Seed #					
	1	**2**	**3**	**4**	**5**	
Bean seed, 4 cm deep						
Bean seed, 2 cm deep						
Bean seed, 1 cm deep						

Table 3. Days to Germination (day seedling first became visible above soil surface).

Part 3: Seed Orientation

1. Prepare three pots with soil. Water with 50 ml of water.
2. Plant 5 bean seeds in pot 1; Orient the seeds so that the radicle is facing up, and each seed should be about 0.5 cm below the surface of the soil when finished planting.
3. Plant 5 bean seeds in pot 2; Orient the seeds so that the radicle is facing sideways, and each seed should be about 0.5 cm below the surface of the soil when finished planting.
4. Plant 5 bean seeds in pot 3; Orient the seeds so that the radicle is facing down, and each seed should be about 0.5 cm below the surface of the soil when finished planting.
5. Let sit for two weeks. Water every other day with 20-25 ml of water (same amount in each pot).
6. Each day during the two weeks, make a note of which seeds germinated first. When calculating averages, don't count seeds that don't germinate (don't average in a zero!)
7. Does seed orientation make a difference as to how fast germination completes (when the shoot first pokes through the soil surface)?

Seed Size	Days to Germination					AVG (days)
	Seed #					
	1	2	3	4	5	
Bean seed, radicle oriented up						
Bean seed, radicle oriented sideways						
Bean seed, radicle oriented down						

Table 4. Days to Germination (day seedling first became visible above soil surface).

Part 4: Seed Hormones (Gibberellic Acid)

1. Prepare two pots with soil. Water with 50 ml of water.
2. Plant 5 bean seeds in pot 1 and 5 bean seeds in pot 2. Each seed should be about 0.5 cm below the surface of the soil when finished planting.
3. Let grow for one week (or until germinated and about 2 cm tall).
4. While growing, water every other day with 20-25 ml of water (same amount in each pot).
5. Once the seedlings have germinated and reached about 2 cm in height, use a Q-tip to apply gibberellic acid to leaves / shoot tips of all seedlings in pot #2.
6. Does application of the plant growth hormone gibberellic acid have an effect on seedling growth rates?

Day	Shoot length											
	Bean seed without Gibberellic Acid added					AVG (mm)	Bean Seed With Gibberellic Acid added					AVG (mm)
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												

Table 5. Average shoot length after two weeks for with and without gibberellic acid applied.

<u>Data Analysis:</u> In part one, graph Time (days) on the X and shoot length (cm) on the Y, using a key so all three treatments (seed size) can be compared on one graph. Secondly, graph Seed Size on the X and Days to Germination on the Y.

For part two, make a bar graph with Treatment (seed planting depth: 4 cm, 2 cm, 1 cm deep) on the X and Days to Germination on the Y.

For part three, make a bar graph with Treatment (orientation of radicle: sideways, up, down) on the X and Days to Germination on the Y.

For part four, make a line graph with Time (days) on the X and AVG. shoot length (cm) on the Y, using a key so both data treatments (with, and without, Gibberellic Acid) can be compared on one graph.

<u>Extensions:</u> For younger kids, just grow a pre-soaked bean seed between a clear plastic cup and paper towel (so, seed is pressed on the wet paper towel, and towel/seed pressed against the inside of the plastic cup, seed facing out so it is visible). Try putting the seed in different orientations (germinating roots come out of the seed's radicle and will grow down, even if radicle points up). Then, every day, measure the length of the roots and shoots. Graph length versus time (day).

For older kids, this can be a guided or open inquiry. With an open inquiry, discuss with the class what environmental factors might affect germination and seedling growth rates. Then, providing materials for a variety of experiments, let the groups decide what and how to test their specific question.

<u>Reflection Questions:</u>

- **Which seeds germinated more quickly – big seeds or small seeds?** (Big seeds have the most energy and often germinate the fastest--especially if they are seeds for annuals. Flower seeds that germinate quickly include sunflowers (4 to 5 days), gloriosa daisy (5 to 10 days), ageratum (6 to 10 days), cosmos (4 to 6 days), sweet alyssum (8 to 10 days), zinnia (5 to 7 days) and marigold (5 to 7 days)).

- **Which seeds germinated more quickly – seeds planted deep, or shallow?** (The recommended planting depth for most seeds is generally 1-1/2 to 2 times the width of the seed, though some seeds must be "surface sown" meaning they should not be covered at all. The deeper seeds have more distance to cover to reach the soil surface).

- **Which seeds germinated more quickly – planted seeds with the radicle pointed down, up, or sideways?** (the embryonic root emerges before the shoot, and emerges from the radicle (the part of the seed that was attached to the ovary of the flower) thus, when the radicle is pointed down the root can start growing immediately in the desired direction (roots respond positively to gravity: gravitropism). But, a seed planted with the radicle pointing up or sideways has to change direction, which uses a lot of energy stored in the seed and decreases the seedling's vigor).

- **Which seeds grew more quickly, plants that had the growth hormone gibberellic acid applied, or those without?** (Gibberellic acid – it is a growth hormone that results in greater cell division and cell elongation).

Models and Explanations: In this lab we explored factors that might affect the amount of time it takes for a seed to complete germination (germination is finished when the seedling pokes up through the soil). **A student who demonstrates understanding** of these concepts can explain why large seeds germinated more quickly than small seeds (they have more food stored in their cotyledons for a boost of growth); why seeds planted with the radicle pointed down germinated more quickly than seeds with radicles pointing in a non-down position (the root grows down; if oriented in another way the root would have to grow and turn around to begin growing down); why seeds that are planted deep germinate more slowly than those planted more shallowly (they had a greater distance to grow before poking out of the soil, which signals the end of germination); and why seeds with growth hormone gibberellic acid applied grew longer than plants without growth hormone added (gibberellic acid causes increased rates of cell division and cell elongation resulting in shoots that grow longer, faster).

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And teacher's packet
http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=9&ved=0CD4QFjAI&url=http%3A%2F%2Fwww.plantingscience.org%2Ffile.php%3Ffile%3DSiteAssets%2FWoS_TeacherGuide_Final.pdf&ei=oEsoVOGvNNCYyASY6YGABQ&usg=AFQjCNHSyQMrSuukaxiBgEPPovije-pJ1A&bvm=bv.76247554,d.aWw

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Student Worksheet:

Flowering plants (and gymnosperms, but not ferns or mosses) come from **seeds**. Each seed contains a tiny plant embryo waiting for the right conditions to **germinate**, or start to grow. Seeds wait to germinate until three needs are met: water, correct temperature (warmth), and a good location (such as in soil). During its early stages of growth, the seedling relies upon the food supplies stored in the cotyledons until it is large enough for its own leaves to begin making food through photosynthesis. Also, all seeds have a built-in ability to orient themselves correctly and grow according to gravity. The roots will grow toward the pull of gravity and the stem or shoot will grow up and away from it. This is known as **gravitropism**.

In this lab we will look at four things: the effects of planting depth, seed orientation, and seed size, on germination of seedlings and also the application of growth hormone gibberellic acid on growth rates of young seedlings. Germination begins with water imbibition (uptake) by the seed and ends when the seedling emerges from the soil. So, once you are able to detect seedling growth, germination has finished and the seedling developmental stage has begun. We will measure how long it takes to complete germination (# of days until seedling pokes through surface of soil) and, for some experiments, measure seedling length. When calculating average time to germination, do not count the seeds that didn't germinate (don't average in a zero, or a high number if the seed never germinated).

Part 1. Seed Size

Question:

Hypothesis:

Prediction:

Day	Shoot length																	
	Grass (small, 1 cotyledon)					AVG (mm)	Radish (medium, 2 cotyledons)					AVG (mm)	Bean (large, 2 cotyledons)					AVG (mm)
1																		
2																		
3																		
4																		
5																		
6																		
7																		
8																		
9																		
10																		

Table 1. Average shoot length after two weeks of growth for seedlings from three different sized seeds.

Seed Size	Days to Germination					AVG (days)
	Seed #					
	1	2	3	4	5	
Grass (small, single cotyledon)						
Radish (medium, 2 cotyledons)						
Bean (large, 2 cotyledons)						

Table 2. Days to Germination (day seedling first became visible above soil surface).

Rates of germination: Grass ____________ Radish ____________ Bean ______________
(size / time)

Conclusion:

Part 2: Seed Planting Depth

Question:

Hypothesis:

Prediction:

Seed Size	Days to Germination Seed #					AVG (days)
	1	2	3	4	5	
Bean seed, 4 cm deep						
Bean seed, 2 cm deep						
Bean seed, 1 cm deep						

Table 3. Days to Germination (day seedling first became visible above soil surface).

Conclusion:

Part 3: Seed Orientation

Question:

Hypothesis:

Prediction:

Seed Size	**Days to Germination**					**AVG (days)**
	Seed #					
	1	**2**	**3**	**4**	**5**	
Bean seed, radicle oriented up						
Bean seed, radicle oriented sideways						
Bean seed, radicle oriented down						

Table 4. Days to Germination (day seedling first became visible above soil surface).

Conclusion:

Part 4: Seed Hormones (Gibberellic Acid)

Question:

Hypothesis:

Prediction:

Day	Shoot length											
	Bean seed without Gibberellic Acid added					AVG (mm)	Bean Seed With Gibberellic Acid added					AVG (mm)
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												

Table 5. Average length of seedling after two weeks when the orientation of the seed radicle is different.

Growth rates of beans without gibberellic acid = ____________________________

Growth rates of beans with gibberellic acid = ____________________________

Conclusion:

Data Analysis:

For part one, graph Time (days) on the X and shoot length (cm) on the Y, using a key so all three treatments (seed size) can be compared on one graph. Secondly, graph Seed Size on the X and Days to Germination on the Y.

For part two, make a bar graph with Treatment (seed planting depth: 4 cm, 2 cm, 1 cm deep) on the X and Days to Germination on the Y.

For part three, make a bar graph with Treatment (orientation of radicle: sideways, up, down) on the X and Days to Germination on the Y.

For part four, make a line graph with Time (days) on the X and AVG. shoot length (cm) on the Y, using a key so both data treatments (with, and without, Gibberellic Acid) can be compared on one graph.

For each graph, identify the independent variable, dependent variable, controlled variables, and control experiment.