BOTANICAL SOCIETY OF AMERICA

THE WONDER OF SEEDS—SPROUT INVESTIGATION

Instructor's Version of the Guided-Inquiry Student Research Guide

Contents

Goals and Background

This is an investigation of seed germination and seedling growth emphasizing inquiry and the scientific process. It is geared for middle school students, with adaptations for high school students. Students are guided through a simple experiment during which they build foundation knowledge on the plant biology and experimental design. Students will germinate seeds and record seedling growth, and compare the results under two light conditions.

Learning Goals and Skills
Providing students the opportunity to explore science as a process and appreciate the role of plants as food sources are core goals of this project. By forming a research question, devising an experiment to test a hypothesis, conducting and analyzing an experiment, students grasp the elements of sound research and practice critical-thinking skills. Students are introduced to the biology content of the project using the research topic as the framework.

Skills: observing, measuring, comparing, describing, analyzing, inferring.

Enduring Understandings

- Because the world relies on seeds for food, the world economy is dependent on plants.
- Seed dormancy and germination are reproductive and adaptive strategies, as well as dynamic processes responsive to the environment.
- Scientific inquiry uses evidence to arrive at new models for biological systems.
- Math is an important analytical tool in the analysis of evidence in science.

Essential Questions

- What role do seeds play in supporting life on Earth?
- How does a sprout develop from a seed?
- What are the characteristics of seed germination and seedling growth?
- What role does the environment play in seed germination and growth?

Biology "big ideas" that can be incorporated
Experiments with seeds offer opportunities to learn many key concepts, including structure and function, reproduction and life cycles, physiology and biochemistry, diversity, and ecology.

- Plants reproduce sexually and asexually. Sexual reproduction involves the alternation of diploid and haploid generations.
- Two groups of plants, gymnosperms and angiosperms, produce seeds as the result of successful pollination and fertilization. Angiosperm seeds are enclosed in a fruit. Seeds are the reproductive dispersal units, containing a plant embryo and food supply. Both the embryo and the food supply are created as a result of fertilization. Various adaptations enable seeds to disperse away from the parent plant.
- One seed has the potential to produce one plant. In the process of germination, the seed sprouts when the embryo becomes metabolically active and uses the stored food.
- Plants respond to and affect the environment. Plant growth is affected by nutrients, light, and water. The orientation of a plant's growth is affected by gravity and light.
- Humans eat a great variety of plants, but mainly about 20 cultivated crops.

The specific learning goals addressed can be tailored according to the class level and student knowledge base. And the experiments adapted to include more or less sophisticated questions and experimental designs. If your students have sufficient background, adapt this project to allow students to develop their own research questions about seed germination and seedling growth.

Possible directions for guiding lower-level students to develop their own research questions

- Compare the germination success and growth rate of a species under different conditions to determine the effect of temperature or moisture (including different kinds of liquids), or the exposure to different color light (place a transparent colored sheet around the growth chamber) or the addition of fertilizer, or seeds planted at different depth of potting soil.
- Compare germination rate of seeds with data printed on seed packets.
- Measure the rate that seeds absorb water
- Look for variation among the seeds of a given species. If they vary in size, shape, color, or other observable difference, record germination success and growth rate among seed types within a species.
- Compare the germination success and growth rate of monocots and dicots.
- Determine how germination is affected by removal of part of the seed (note which part), or how growth is affected by removal of part of the cotyledons.

Possible topics to incorporate in modifying the experiments for upper-level students

- Describe gravitropism and have students devise experiments to see how roots respond to changing orientations.
- Examine the effect of pollutants by recording germination and growth of seeds in control pots and pots polluted with non-biodegradable dish soap, oil, salt, pet waste.
- Explore what seeds are present in the seedbank, then devise experiments to compare the percent germination and rate of growth between invasive and native species, grown separately and together.
- Evaluate how oxygen and carbon dioxide levels change when seeds respire.

Background on Seed Germination and Seedling Growth

A seed is a ripened ovule of a fertilized flower. Seed morphology varies enormously, but all seeds contain the diploid embryo and a food supply. Most seeds have a protective outer seed coat enclosing the embryonic root (radicle), the embryonic stem (hypocotyl), and the seed leaves (cotyledon). The number of cotyledons differs among plants that produce seeds. It is variable in gymnosperms. The number of cotyledons in angiosperms is either one (in monocots, such as corn, grass, onions, lilies) or two (in dicots such as beans, sunflowers, tomatoes). Dicots store their energy reserves in the cotyledons. Monocots store their energy reserves, which are usually high in starch, in the endosperm. The seed coat of monocots like corn is fused to part of the ovary wall, so a corn seed really includes part of the fruit. These "seeds" are sometimes called grains or cereals.

Seeds remain inactive in a dormant state until environmental conditions are favorable for germination and growth. The environmental conditions that are favorable for one plant are not necessarily the same for all plants. Plants are adapted to different environments. The genetic makeup of a plant influences when it reproduces and how it responds to external factors such as temperature, moisture, and light.

The first step in germination is a dry seed absorbing water and swelling, which is called imbibition. Water softens the seed coat. Water also activates enzymes in the plant embryo and it becomes metabolically active, using its stored food supply to fuel its growth. The root sprouts first, out of the casing and downward as it responds to gravity. The stem and leaves then sprout, growing toward the sun and shedding the casing.

The stem elongates and the roots grow deeper (a process called primary growth) as cells in the apical meristems divide, elongate, and differentiate.

General Plan

A minimum of two weeks is needed for this inquiry. It could easily be extended to three or four if students design a second experiment using knowledge gained from the first.

Each student will responsible for growing seeds over this period, but students should work in teams of 2-4 to post journal notes and data to the online site. Decide how you would like to organize your class into teams, so that a variety of sprouts are studied and each sprout species is studied under two light conditions. For example, the four members of Team A study sunflower seeds, with two members testing ambient light conditions and two members testing weak, indirect light conditions. The Team B studies oats, Team C studies alfalfa, etc.

Day 1—**Engage and explore prior knowledge** (45 minutes)

- Introduce topic of seed germination and seedling growth.
- Engage students and connect lesson to everyday life and relevance to society
  Brainstorm with students about ways that seed biology might be important to society. (Examples: conservation, crops, ornamentals, tree farming, etc.)
- Probe for prior knowledge
  Ask students what they know, think they know, and want to know (KWL) about "spouting seeds". A good starting question is "Where do seeds come from?"
- Explore seed diversity, seed, structure, and seed function
  - Have students examine different types of seeds to compare and contrast their shapes, colors, sizes, etc.
  - Soak lima beans the night before class, and in class have students dissect the seeds to locate the embryo, then draw and label what they see. Follow up this activity later in the project, by having students dissect a selection of seeds used in the sprouting activity.
  - Play the "Branching Out" segment of David Attenborough's *Private Life of Plants*, a 6-part BBC Television series, which is available on video or DVD.

Day 2—**Introduce scientific inquiry** (45 minutes, or combine with day 1 for longer sessions).
[Asking questions about sprouts and thinking about research plans are included in the Step-by-Step Research Guide. Students could transfer handwritten notes into the journal if you prefer not to use the Research Guide during this exploratory phase.]

- Facilitate a discussion on what it means to what it means to "sprout" or germinate and "grow." Brainstorm with the students: "Why is spring the time of year when we see many seedlings and new growth?" "Why is light important to plants?" Facilitate a discussion on light, temperature, and moisture as factors that create favorable conditions for germination and growth.
- Ask students "What is a good measure of "sprouting?" What is a good measure of "growth?" Introduce control and test variables. Discuss inquiry and the scientific process in the context of designing their experiments.
- Introduce the essential components of research (careful observing, note taking, and data recording, as well as sharing ideas and results with others).

Days 3-13 or so—Student Research, as described in the Step-by-Step Research Guide

Day 14—Graph Preparation and Poster Preparation

Day 15—Presentation / Class discussion (What do the class findings tell us about seed sprouting? What new questions do we have?) / Inquiry Assessment

Expectations

You may modify this lesson plan any way that better suits your students. However, we ask that you use inquiry-based or guided-inquiry teaching practices when you carry out this lesson. This version is structured for guided inquiry. The following expectations are based on the lesson as described in this research guide and should be modified if you modify this lesson. **[The expectations are not included in student version, so that you can customize them before handing out.]**

In this project you have the opportunity to:

- Observe seed structure; document parts of growth cycle from seed to plant.
- Explore diversity by comparing seed morphology, seed dispersal mechanisms, and seedling growth of several plant species.
- Discover how to grow and care for sprouts.
- Gain a sense of the interdependence of life on Earth through the use of sprouts as a food source and economic crop.
- Explore the scientific method by asking and refining research questions.
- Collect data using both quantitative (measurement) and qualitative (observation) skills.
- Communicate your experiment and its results, and comment on work of others.

As you go through the Research Guide, you will be doing "real science." This means understanding the main points, reasoning carefully, being systematic in recording information, using the tools of research, working as a team, and communicating well.

You will be expected to:

- Complete the Research Investigation described in the Student Research Guide
- Participate fully as a member of the research team and of the scientific community
- Correspond with scientists online
- Produce a Poster Presentation as described in the Poster Guide
- Assess your own work and provide feedback to your fellow students

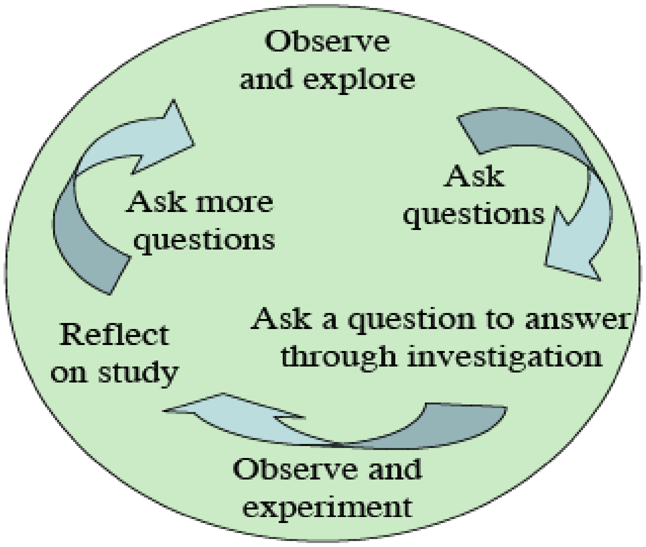
Note: If students devise their own experiments, they should be expected to articulate a research question, collect data, and report findings. Students should identify a question that can be tested, specify the variables used in the experiment, and the data to be recorded. Their data collection should include multiple trials, an obvious pattern, and a reasonable conclusion.

Although a sample data sheet is provided, help the students understand that one data table would not work for all experiments. Encourage students to devise data sheets that fit their experiment.

While most students need to have an answer, it may not be possible to see differences with their experimental conditions. It is acceptable to state that no difference was observed.

With teams running separate experiments in parallel, it would be very meaningful to have a "germination and growth seminar" for them to share their results with their classmates.

Inquiry as a Cycle, Science as a Process



The Inquiry Cycle
Never Ends.

One good question leads
to many more!

Inquiry begins with 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 cycle, all questions are good questions. The more you wonder about something, the better.

Scientific inquiry is a special case of inquiry. Scientific inquiry relies on understanding basic concepts to reach a testable research question. Through the initial engage and explore activities, you will begin to build this knowledge base. Conduct your own background research to further develop it.

Selecting a question that can be answered through investigation gets easier with experience. The why questions are really difficult. The how, what, when, and where kinds of questions are more answerable (testable). “Why are there so many kinds of plants?” We might never know the full answer to that fascinating question. But we can get a handle on questions like “Where is plant diversity highest” and “What environmental factors influence plant diversity” and “How do invasive plants impact native plant diversity.”

Once you have selected a testable question, then you need to decide the best research method to test it. This is the stage in the process where you develop your research plan and experimental design. Observing nature carefully and taking notes about what you see can answer some questions. Other questions are better answered by experimenting--manipulating conditions. The condition that is manipulated by the investigator is the independent variable of the study (e.g., light conditions). The factor that is being measured by the investigator is the dependent variable (e.g., plant growth).

Creativity is highly valued in the scientific community. Big breakthroughs often come when a researcher looks at a problem in a new way, or tries an innovative method to answer a question. Equally, if not more important, is being careful and systematic in thinking, planning, and measuring. If you are interested in testing the effect of light on plant growth, it is important that other conditions like temperature and moisture are the same for all samples in your experiment.

The data you collect serves as the “evidence” that you must interpret and use as a basis for your conclusions. Consider the results carefully. Reflect on every part of the investigation. Then share your ideas with others, get some feedback from them, and review the work of your peers. You can learn a lot by comparing your work and talking about it.

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 to others to answer bigger questions.

How To Grow and Track Sprouts

Materials

- seeds to sprout
- growth chamber (1-liter plastic bottle, with top portion cut off, for each student)
- box large enough to hold growth chamber, with small window cut out of top (for half of the students)
- 1 piece of screen or netting
- rubber band or ring for growth chamber
- journal for documenting investigation
- data sheet for recording growth
- Internet access for uploading journal, comments, and data

You will be each responsible for sprouting seeds in a growth chamber as part of a class experiment. Some of you will keep your growth chambers on a windowsill. Others will keep your growth chambers in boxes that have a small window at the top. As a class, you will be conducting an experiment to explore the role of light on plant growth.

1. Make a note of the species you will be growing on a Sprout Tracking Sheet. Note the light condition you are testing, and your name and your Team's name.
2. Take a close look at the seeds and describe them. Look at your classmates' seeds and make notes about their size, coloring, and shape.
3. Count the number of seeds you have and enter that number on the Sprout Tracking Sheet.

   [NOTE: Depending on the size of your growth chamber and seeds, you will use anywhere from 1/4 teaspoon of seeds to 1 tablespoon of seeds. A good rule of thumb is use enough to cover the bottom of the container with one layer of seeds.]
4. Add the seeds to your growth chamber. Label your growth chamber with your name and the start date of the experiment.
5. When you get back to your home, pour enough water in the growth chamber so that the seeds are all under water and have at least 2-3 cm more over them.
6. Put the growth chamber either on a windowsill or in a box.
7. In the morning, empty the water, and make a note of any changes you see. This step allows the seed to absorb (imbibe) water and starts the germination process. Make sure that you remove excess water droplets. Wet sprouts will rot instead of germinating. It is helpful to let them drain upside down for a minute or so. Be gentle as you swirl the germinating seeds to rinse them.
8. Each morning for the next 13 days, rinse the sprouts once a day. Gently run water into the growth chamber through the netting and gently swish the seeds in the water. Dump the water out and gently shake the growth chamber to remove excess water droplets. It is

helpful to let them drain upside down for a minute or so. Record any changes you observe. Return the growth chamber to its location once you have rinsed and observed the seeds.

9. Once the seeds have begun to sprout, measure the length of one sprout (in cm) every day. It is likely your sprouts will not grow perfectly straight----Can you think of a good way to measures something that is not straight?

Over the course of two weeks, closely observe the growth of the seedlings and document our observations daily on your data sheet. Be sure to make note of the first day the root is visible, the first day the shoot is visible, and the first day that true leaves appear.

On day 14, graph the sprout growth data you have collected in Excel (See the help sheet at the end of this document).

Sample Data Sheet
(use this sample or create your own)

Sprout Tracking Form for: ____________________ **Member of Team** _________________

Sprout name ________________________________ **Number of seeds** _________________

Seed description:

Description of experimental conditions:

Date	**Rinsed**	**Length (cm)**	**Seed swells, seed coat cracks, roots, shoots, leaves visible?**	**Other Observations**

Happy sprout farming!

Step-by-Step Research Guide

1. Keep a record of your team's investigation in your JOURNAL.
This guide will help you think through your research problem. To answer each of the questions use careful reasoning and systematic thinking! Remember to use any observations or experiences from everyday life, as well as scientific facts and evidence to help you consider your ideas. Write in the journal any time you want to bounce around new thoughts or ideas. Don't be bashful! Every scientist has been wrong many, many times in their career! The challenge is finding out how things really work!

Your journal (or laboratory notebook) is the long-term record of your work. Record in it everything someone else would need to know in order to re-create your experiment. Keeping careful records of ideas, research plans, and research results is very important.

In your first journal entry, record your school and team name. List the first names of the team members. Be sure you include the date for each new entry in your journal or data sheet.

[Note that each team has a blank MS Word journal on their team's web page, a sample is given below. Click on the Our Journal link to access this sheet, save this sheet to your computer, and begin using it to record your investigation. Each team has a blank MS Excel sheet on their team's page. Click on the Our Data link to access this sheet and set up a data sheet that matches your team's research question. See the WebGuide for further details on saving and uploading it.]

Example Journal Page with first entry
County School, Team 1—Jessie, Tryna, Ulrich, Reilly

Date

2. Explore the basic research problem you will be investigating.
The research problem is the general topic you will be investigating. In this case, you are exploring seed germination and seedling growth. Before you begin to refine your research, take a close look at the different types of seeds and ask yourself some general questions.

How do they differ in appearance (size, color and shape, etc.)? If you cut open a seed, can you identify the parts?

Which species do you think will germinate first? Why do you think so?

Grow longest? Why do you think so?

Have the highest sustained growth rate? Why do you think so?

3.   Research your problem, your plants, and your experiment.
Research is not just an experiment. Scientists use books, periodicals (which they call "journals"), and research reports from other scientists to study their problem. This process is called background research.

Use the "How to Grow Sprouts" sheet to help you understand how sprouts are grown. You can also look at the links under "Resources" to gather more background information. List the important facts or ideas you know or think you know about sprout growth before starting your research.

Here are some starting questions to start you thinking about sprouts.
a. What are monocots and dicots? Is your sprout a monocot or dicot?

b. Why do we need to rinse the sprouts daily?

c. Is measuring only one sprout a day a good way to collect accurate data? Why or why not?

As you do your background research, write down what you discovered in your research. These are notes and not a final draft, so lists, incomplete sentences, etc. are fine. Record your background research in your journal. Note who contributed each piece of information or idea.

Example Journal Page with background research
County School, Team 1

Date

Our Background Research

What we know or think we know about sprouts: (You may not know where some of these facts or ideas come from. That's okay.)

Fact 1 (sprout sheet) - Jenny
Fact 2 (my experience or observation) - Marcus
Fact 3 - Jamsheed

What we discovered from reading: (Make sure to write down the link or sheet title from which you got each piece of information and the team member who contributed the item.)

Fact 1 (botany book title and author, page number) – Jamsheed and Ayesha
Fact 2 (web link URL, title) - Marcus
Fact 3 (etc) - everybody

4. Identify questions that interest you.
Based on your class discussion and background research, what do you WANT to know about sprout growth? Write them down in your journal. Note who contributed the question.

Example Journal Page with Research questions that interest your team
County School, Team 1

Date

Question 1: Will the smaller seeds germinate faster than the larger ones? – Jamsheed
Question 2: YYYYYYY – Ayesha

Hypothesis 1: Temperature will affect the germination rate of seeds – Tonya

Teacher hint: Encourage students to use the evidence from their background research to formulate questions. Even if their questions are expansive, have them write them down. Then have them think them through to somewhat more manageable questions from which research questions are more easily extracted (below).

5. Work as a team to state the research question you will test as a team and describe the research plan to test it.

Things to consider in developing your research plan:

- What kinds of data will you be collecting?
- What tools and methods will you use to collect your data?
- What will your data look like?
- In what format will you collect your data (table, chart, etc.)?
- Also remember that description (qualitative data) is just as valid numerical data. What kinds of observations can you make and record in your experiment?

IMPORTANT QUESTION: As you plan your experiment, keep asking yourself, "DOES YOUR EXPERIMENT ADDRESS YOUR RESEARCH QUESTION?" If you get off-track, just go back and tweak your experiment to focus back on the question.

Example Journal Page with Research question or hypothesis and research plan
County School, Team 1

Date

Our testable research questions.
Do seeds germinate faster under light or dark conditions?
Do sprouts grow at the same rates in light and in dark?

Our hypothesis (this is possible explanation for what you observe/or know from reading) is…

Our prediction (this is what you expect to see) is…

Our research plan.
The variables we will test… (what will be manipulated? What held constant?)
The things we will measure &/or count…
The things we will observe..
The way we will record the data

Teacher hints if students have the opportunity to select a question to investigate:
Some obvious questions

- *How fast do sprouts (species) grow? (length over time)*
- *How long does it take for a seed to germinate? (days to germination; what does the benchmark for germination look like?)*
- *Do the same kinds of seeds germinate at the same rates? (days to germination)*
- *Do all seeds of one kind germinate or do some never seem to germinate (seed viability as a function of species, monocot vs. dicot, etc.)*

Less obvious questions:

- *Does dry mass change as sprouts grow? How does dry mass relate to length over time? (If students examine this question, make sure they have enough sprouts started to dry for each data point.)*

Some students may ask why sprouts are grown in the dark, when we know that plants need light to grow. Encourage them to explore their inquiry as growth rates must still be measured and analyzed using identical methods in light and in dark. Other students may want to know about growth of sprouts in soil. Does the anatomy of dark, light, soil-grown seedling sprouts differ. If so, how? Students will have to deconstruct their questions into simpler ones that they can test experimentally. Guide students from expansive "why" questions to testable "how" questions.

Put out the tools and instruments that students will have access to in conducting their experiments. Show them to the students. If students have ideas that require other *tools/instruments and they can bring them to class or you can acquire them easily, consider expanding the options on a team-by-team basis.*

Have the class gather and hear each other's research questions. Have each team justify their question with evidence whenever possible. This activity will prepare them for the final "debate" over their experimental findings and models for seed germination and seedling growth.

Make sure that students do some qualitative data recording. Encourage drawings or photos of seeds at their different stages and dissection of seeds to determine what's going on in the germinating seed.

Teacher-Initiated Activity: At this point, students often have constructive ideas on how to improve each other's work. This is especially true if students have had limited experience in designing their own experiments. Teams can circulate among other teams to "hear" about each other's experiments and give feedback to research teams. Students can then choose to modify their experiments based on input from other teams. Alternatively, reviews can be carried out online by reviewing team journals. Students can use the Inquiry Cycle model and the model of the Scientific Process (see Pre-Inquiry Guide) to focus their critique. Caution students against making superfluous comments, as it does not help other teams to improve their designs.

Teacher Hint: This may be a good time to call on experts to review the research question and experimental design. Scientists can give students feedback in various ways. If you have a specific concept that students are having difficulty with, you might ask the scientist to focus on this concept in reviewing the question and design. Alternatively, you might have the scientist "talk" about their research with your students online. This should be done once their experiments are in progress, so that it doesn't alter the students' from initiating their own questions.

Teacher-Initiated Activity: As a class, have the students present their questions and experimental designs. Discuss comparing data across teams. Do the types of measurements and units make the data comparable? How can students tweak their experiments to make data comparable across different types of experiments going on across the classroom and with other classes who might be doing this investigation?

6. Start your experiment and record your data and upload your data regularly (say twice a week) on your team's page on the BSA's website http://www.botany.org/scientific_inquiry/. Gather the materials, tools and instruments for your experiment. Have your data collection tables, charts, etc ready. Begin recording your data.

IMPORTANT! Record anything you might observe that you think might influence this data point and any human error that might have occurred to make the point less reliable.

IMPORTANT! You might notice something toward the beginning of your experiment that might be an important factor in figuring out what your experimental data mean. Sometimes you can modify your experimental design even after you start your experiment to add this new observation. For instance, you might notice something about seed size or that only half the seeds actually sprout. If you don't consider these types of data when you design your experiment, note them in your report and ask your instructor if you can add the data some way to your results. This kind of careful observation and notetaking during an experiment can be a good source of new experiments and great discoveries later on!

Teacher-initiated activity: When students have down time, they can continue to comment on other teams' experimental designs and research questions at the website. Students should reflect on experiments in the context of the inquiry cycle and scientific process.

7. Summarize and analyze your data.

The data you have recorded in your data sheet is what scientists call "raw data". The data must be put into a format in which scientists can easily compare data and visualize data. This usually means a graph of some kind.

Teacher Hint: See the Math Explanation in the Appendix for a discussion on the various math concepts important for data analysis. This might be a good point to begin online discussions with the mathematician.

8. Make meaning or sense of your data. Explain it.

Report a summary of your data in your journal. Stop and think about your results. Feel free to find out what other teams have discovered and try to fit the relevant experiments from other teams into your picture of how seed sprouting works.

Give an explanation of the data in your online journal. Make sure to use your evidence (experimental findings) to backup each point of your explanation. Explain your thinking about how you arrived at this explanation. If you use evidence from another team's experiments to further extend or support your explanation, make sure to cite them in your report.

Example Journal Page with Research results

County School, Team 1

Date

Summary of our results.

How many days until the first seed germinated?

How many days until 95% of the seeds germinated?

How many seeds had not germinated by the 14th day?

What percentage of seeds germinated?

How many days until it produced a root?

How many days until it produced its first shoot?

How many days until it produced a first true leaf/blade?

What is the length of the largest leaf/blade on day 14?

Explanation of our results.

Do you accept or reject your hypothesis regarding the species that will germinate first?

Do you accept or reject your hypothesis regarding the species that will grow the longest?

Do you accept or reject your hypothesis regarding sprout with the highest sustained growth rate (equal amounts of growth over all days, rather than one big growth spurt)?

9. Prepare a scientific poster about your research and post it to the website and to your class

Scientists do this in the real world. Scientists sometimes perform almost identical experiments. In fact, this is routine. It helps to confirm and solidify the evidence base for determining how things work. *Teacher hint*: If some of the faculty members have posters that you can bring to class or hanging in the hallways near their offices/labs, show them to students as examples of the real-worldness of posters. They can also use them as good examples to work from.

Teacher hint: Students should support their explanations with evidence or known facts from their background research. This type of sensemaking is the core of science. Again, help students make the distinction between what they KNOW is true from fact and evidence to what they THINK might be true based on inference from partial evidence. Students may be comparing light/dark growth (measurements) over time, as well as changes in form (morphology) over time in light/dark conditions.

Teacher Hint: This is an excellent place for scientist input. Scientists review posters at large conferences every year.

10. Give online feedback to your fellow research teams about their posters.

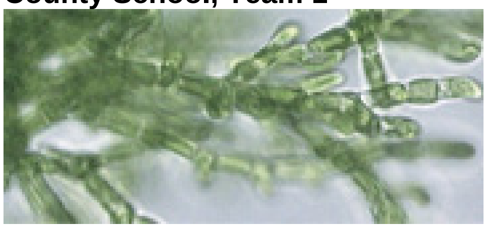
Useful input might be how your findings might relate to theirs, if at all, and what you might have been thinking about the same problem or question. Also, in critiquing, use the definition of inquiry to help guide your comments. Did the team make careful observations? Did their experimental design address their research questions? Did they collect and analyze their data adequately? Did their explanations make sense with respect to their data? Did they plan and reason carefully?

*Teacher-Initiated Activity***:** Have students give online feedback on posters by other students in the class. Also have students give feedback to other classes at your school or other schools even if reviewers are from different grades than your own class. Have them use the inquiry definition as some of their critiquing points. Also have them give feedback to other classes at your school or other schools even if reviewers are from different grades than your own class. Have teams present their poster. Have the class assess the presentation (see Assessment Guide).

11. Compare your data to other teams in the class and reflect on your experience and derive new questions from your experiments.

Consider what you have learned from germinating and growing sprouts. Enter your new questions and some of the questions that resulting from the class discussion in your online journal. Remember to give your explanation for how you and/or the class came to that question.

Example Journal Page with Reflections on Sprout Farming
County School, Team 1



Date

Things we have learned about plant growth and development through investigation.
Here are some possible items to consider:

How does monocot development differ from that of dicots? (Development refers to how sprouts grow, what order do structures develop in? What structures do you see as it grows?) Do your sprout observations support these definitions or not?

What have you learned about caring for plants as a result of this project?

Based on the class data, what factors do you think most influence a seed's ability to germinate and grow into a plant? Why do you think so?

New questions we have.

Any additional observations/comments on this project?

Teacher-initiated activity: Have students debate or generate a lively class discussion about the models for seed viability, germination and seedling growth. Make sure students understand their data and can call on evidence from their experiments or the literature to support their debating point. To familiarize yourself with debate procedures, see http://www.educationworld.com/a_lesson/lesson/lesson304.shtml

Measuring Stem Length

Measuring "sprout" length can be challenging because of their irregular shape. Here is an easy way to make a length measurement. You may want the students to figure this out for themselves or you may want to add it to their guide before printing it out.

- Take a piece of dry string.
- Trace the shape of the "sprout" with the string noting where the "sprout" begins and where it ends.
- Measure the length of the string between the two end points.

If time permits, let students figure out how reliable this method is. What factors might produce erroneous results? What might produce poor replicates? Would something other than string produce more reliable and reproducible results?

Microsoft Excel: Entering Data and Creating Graphs

Entering Data on a Spreadsheet

When you open Excel a spreadsheet will appear. This is where you will enter your data, which will later be made into a graph.

- Column A will become your X axis. **Number each box in column A from 1-14** to represent days. To number quickly **type 1 in box A1** then **type =A1+1 in the *fx* box** at the top of the screen, then **highlight boxes 1-14** and the numbers will appear.
- Column B will become your Y axis. **Enter your data** by clicking on the boxes in column B one at a time and typing in your sprout length in cm for each day beginning with day 1 in box B1 and so on down the column.

Making a Graph

- Once all your data is entered on the spreadsheet, **highlight both columns A and B** by clicking and dragging across all of the boxes you entered, then **click the graph icon button** in the menu at the top of the screen.
- Select **Line Graph** from the Chart Type menu.
- **Select the second option down on the left**, "Line with markers displayed at each data value", from the Chart Sub-Type menu**. Double click it.** A preview of your graph will appear.
- Click on the **Series tab** at the top of the preview graph, highlight **Series 1** and hit the **Remove** button below it. This will make the blue line disappear.
- Click **NEXT.**
- Now it will ask you to title your axis. **Under X Axis type "Day", Under Y Axis type "Length (cm)"** in the boxes to the left of the graph. **Title the chart with the name of your sprout.**
- Click **NEXT**
- Select **As New Sheet**. Now your finished graph will appear.
- **SAVE** to your hard drive and to a disc to bring to class.

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