BOTANICAL SOCIETY OF AMERICA

THE WONDER OF SEEDS—SPROUT INVESTIGATION
Instructor's Version of Student Research Guide

Contents

Botanical Society Of America

How to Grow Edible Sprouts

1. Place seeds in your sprout growth chamber.
2. Fill chamber with enough water to cover seeds with 2-3 cm of water.
3. Put sprout chamber in a dark, warm place overnight. (A closet or cabinet will work.)
4. In the morning, empty water from sprout chamber. Rinse sprouts several times with clean water. Drain upside down for a minute or two. Remove excess water droplets to prevent sprouts from rotting.

Expectations
(NOT INCLUDED IN STUDENT VERSION,
so that you can customize before handing out)

You may modify this lesson plan any way that better suits your students. However, we ask that you use inquiry-based teaching practices when you carry out this lesson. The following expectations are based on the lesson as described in this research guide and should be modified, if you modify this lesson.

Students will be expected to:

- Complete the Research Investigation as described in the Student Research Guide
- Participate fully as a research team member and a member of the class scientific community
- Complete all written work (both online and paper) as described in the Student Research Guide.
- Perform self-assessment
- Perform peer reviews
- Correspond with scientist and math experts online
- Produce a Poster Presentation as described in the Poster Guide
- Provide students at other schools with feedback on their experimental designs and poster presentations and exchange research findings with them.

What to tell students:

- Students will be coming up with their own research questions and designing their own experiments. This is not a cookbook lab.
- Investigations will be conducted in teams and they will be held accountable both as individuals and as teams.
- Teams will come together at the several points in their investigations to discuss experimental design, data analysis and final presentations.
- Students will be assessing themselves and their fellow students on the science and scientific practices (which you will be talking about in a moment)
- Above expectations

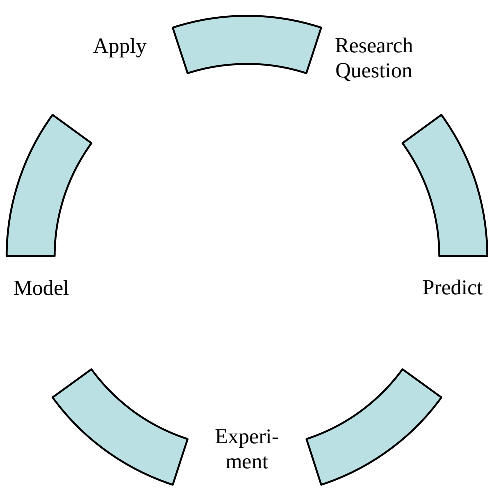
The Cycle of Inquiry

BEFORE STARTING THEIR INVESTIGATIONS

Tell students that they are going to be designing their own investigations. But first, they should be familiar with the research process, i.e., the inquiry and scientific process model.

Introduce the Inquiry Cycle as "the way scientists do their investigations"
In order for students to conduct their inquiry successfully, they must pay attention to the inquiry cycle to make certain that they approach the inquiry with a certain amount of rigor. Countless students have done many experiments and written lab reports in a rote manner without understanding how science works. This time you spend with them talking about the inquiry cycle and the scientific process will help the assess themselves while designing their experiments, running them and drawing conclusions from their evidence and applying those conclusions to the bigger picture of biology.

Students may not be familiar with the "parts" of the inquiry cycle. They will be assessing themselves and their classmates (see Assessment Guide) on those qualities that demonstrate good use of the scientific inquiry process. The Inquiry Cycle is repeated with each new research question. As students develop their inquiry abilities, some of the scaffolding can be removed leading to more independent learners. This model is based on the one developed for the ThinkerTools project in physics.



- Model of Scientific Inquiry Process
  This is the model that students use to guide their research. As they go through the Research Guide, they will in effect be addressing its components:

- Understanding the Main Ideas – Students must understand the main ideas to get to a testable research question that rests on a firm base of existing scientific evidence. In this lesson, the engage/explore activities along with their background research will form the basis for formulating their research question.

- Understanding the Inquiry Process – Understanding the inquiry process will encourage students to rely on evidence to formulate questions and interpret data in the context of existing evidence. First, students must view their data as evidence and arrive at interpretations and conclusions based on their evidence. Next, students apply their evidence to their model of seed germination and growth to modify their working model for this process. This "apply" is the apply of the inquiry model.

- Being Inventive – This is a highly valued quality in the scientific community. By using creative methodology, approaches and analytical tools and making creative connections to other fields, scientists make great advances.

- Being Systematic – Doing science is about being systematic in examining and manipulating variables in experimental design. Being thoughtful and careful in thinking and planning are equally, if not more, important characteristics of the scientific process.

- Reasoning Carefully – Critical thinking and taking the evidence base and all possibilities into consideration are hallmarks of good science. Students must learn to reflect on their own thinking, while debating and incorporating other student ideas into the base of evidence.

- Using the Tools of Research – What are the key tools of research that students can use in this investigation? Help them identify what some of them might be. Math is one of the key tools in science. Using math correctly and creatively makes sound science.

- Teamwork – Scientists routinely work as teams and teams communicate with each other to build the information base and models. Scientists often collaborate across fields of expertise to broaden the research questions they can ask and to connect their research questions to the bigger questions in biology and science in general.

- Communicating Well – Science does not occur in a vacuum. In order to refine and expand conceptual models within and across disciplines, scientists communicate their findings through publication, presentations to peers, and review of peer work. This process also allows for peer review, a checks-andbalances process by which scientists check and question each other's work to make certain that integrity is maintained.

NOW YOU ARE READY TO HAND OUT THE RESEARCH GUIDES AND EXPLAIN HOW IT'S ORGANIZED.

BOTANICAL SOCIETY OF AMERICA

Step-by-Step Research Guide

1. Record all of the work described in this guide in your team's ONLINE JOURNAL.

You can do this by first recording it on paper or an MS Word document and uploading/emailing it, or typing it directly into the online journal. Your instructor will give you specific instructions on the most effective way to accomplish this.

This guide will help you think through your research problem. Answer each of the questions thoughtfully and carefully, since the Inquiry Cycle and Model for Scientific Process emphasize 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. We also want you to write in the journal any time you feel like you want to bounce around new thoughts or ideas. In the real world of scientific research, every idea is considered. So don't be bashful! Every scientist has been wrong many, many times in their career! The challenge is finding out how things really work!

2. Identify the basic research problem you will be investigating.

In other words, what is the basic research problem you are investigating? You do not have to have a specific research question yet. The research problem is the very general topic you will be investigating. In this investigation, the research topic is "sprout growth" as you discussed in class previously.

3. Research your problem.

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 Edible 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. Then as you do your research, write down what you discovered in your research. These are notes and not a final draft, so lists, incomplete sentences, etc. are fine.

Example background research page:

Background Research

What I know or think I know about sprouts: (You may not know where some of these facts or ideas come from. That's okay.) Write down who on your team contributed the idea.

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

- *:*

What I 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.)

Example: Facts and ideas from reading

- *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 research, what do you WANT to know about sprout growth? Write them down in your journal. Note who contributed the question.

Example: Questions we have about sprout growth

Question 1: XXXXXXX – Jamsheed
Question 2: YYYYYYY – Ayesha

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 identify one team question that you can test experimentally.

Teacher Hint: Students often focus on experiments that produce quantitative data. However, biology was originally borne as a descriptive science. Students should be encouraged to combine qualitative data obtained through observation and documenting those observations through drawings and descriptions with their quantitative studies.

Hint: You may have to break down your questions into smaller questions to find one that you can test. Consider the materials, tools and instruments that are available in your classroom. Consider materials, tools and instruments that you might bring from home, if what you have in the classroom is not adequate. Check in with your instructor about the availability of things you don't have. What is your working model for "seed sprouting"? Write down your research question. Check in with your teacher.

Example: Team Research Question: [write question here.]
Working Model: Describe. Include drawings and diagrams.

Some obvious questions

- How fast do sprouts (species) grow? (length over time)
- Do sprouts grow at the same rates in light and in dark?
- 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.)

Teacher hint: 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.

Teacher Hint: 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.

Teacher-Initiated Activity: 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.

6. Design your experiment. Write up a template for your preliminary lab report.
A template is the format for your lab report. The template is a PLANNING TOOL for your experiment. It helps you gather the right equipment and have things ready to go. Items you know about and use for planning, such as materials, methods, empty charts and

tables, etc. should be part of this template. You will fill in the data as you perform your experiment. An example is shown below.

Things to consider in constructing your template and 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? [Teacher hint: 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.]

Your lab report is still a draft! Do not worry if you need to modify as you actually run your experiment. But DO take the time to think this through carefully. Scientists do not want to waste time and expensive materials doing poorly planned and poorly thought out experiments.

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: Seed Investigation Preliminary Lab Report

Research Question: [State your team's question here.]

Prediction: What do you think the answer to your research question will be? Give your reasons for why you think this is so? Use your background research and what you know to support your predication.

If you don't have a strong prediction, just make one. Describe what you think the supporting and non-supporting evidence might be for your prediction. Science is about testing the prediction and it doesn't matter whether your prediction is right or wrong. What matters is that an answer is obtained that helps to create a bigger picture of what's going on and how things work.

Materials: Seeds (What kind? How much?)
Growth Chamber (How many?)
Instruments/Tools
Etc.

Methods: Step-by-step instructions for your experiment.

Consider the number of data points you will take for each measurement. Do scientists base their thinking on one point or do they do replicates? What are the benefits of replicates? Record your thought in your online journal.

Kinds of data: List the factors you think are important for your seed sprouting and the data that you want to record.

Formatted data: Create your charts, tables, etc ahead of time, so you aren't scrambling when you need to record something on a moment's notice. Label the headings and units.

Timeline: Create a schedule for each part of your experiment.
Day 1: Set up
Day 2: Collect and report data point X
Etc. How many days will you collect data? Will you have enough class time to do so? Check with your teacher.

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.

7. Bullet-proofing your experimental design.
Go through each step of your experimental methods (step-by-step instructions). Picture each step in your mind. What materials do you need for that step? Is the material listed in your "Materials" list? Do you have units written down for your different types of data?

Make sure to consider the environmental factors in describing your experimental conditions for sprouting. Will you be doing your experiment in the light or dark? What instruments or tools will you use to make measurements and collect data? Be thoughtful and thorough in thinking through your experimental design.

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?

8. Prepare to run your experiment.
Gather the materials, tools and instruments for your experiment. Have your data collection tables, charts, etc ready.

9. Start your experiment.
Create a Results section in your Preliminary Lab Report. Record the data in your online lab report.

- Date and time of data entry.
- 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 note-taking 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.

10. Enter your data into your team's page at the Wonder of Seeds project on the BSA's website http://www.botany.org/scientific_inquiry/.

11. Analyze your data.
What you have collected 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. If you know how to use MS Excel to enter and graph data, do so. The Excel file can be sent to the website in place of entering the data on the data submission form.

Teacher Hint: An Excel "how to" file is included in the Teacher Resource area.

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.

12. Make meaning or sense of your data. Explain it.
Look at your observations (descriptions) of change over time. Some observations will be descriptive text (words), while other observations will be numerical. What story do the non-numerical data tell? What story do the graphed numbers tell? Explain each in detail. What are you sure about in each of your stories and why? What are you less confident in each and why? Explain what your data says about seed sprouting. 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 this 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.

13. Prepare a scientific poster about your research.
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. Identical experiments lead to data that can be compared directly (or almost). When scientists perform experiments that ask slightly different questions, they work together to connect pieces of their model together. For instance, one lab's work might describe where a certain species of tree occurs around the world. Another group might find that a rare species of fungus grows under this species of tree. The tree group then finds that their tree species is threatened by clear-cutting in areas where this tree is found. The two teams of scientists then work together to determine whether the rare fungus will become endangered as a result of deforestation. In creating their models of how things work, scientists always use their data as evidence to support the model. Science is based on evidence, not on made-up fantasy. In science, what we call the model is sometimes referred to as a working model or working hypothesis because as new findings are made, the model is modified to account for the new evidence.

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.

14. Post your poster to the website.
*Teacher-Initiated Activity***:** Have students give online feedback on posters by other students in the 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).

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

15. 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?

16. Present your poster to the class.
*Teacher-Initiated Activity***:** Use the inquiry assessment tool here.

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 teams present their poster. Have the class assess the presentation (see Assessment Guide).

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

17. Compare your data to other teams in the class.
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

18. **Derive new questions from your experiments and experience.**
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.

Measuring Stem Length

Teacher Hint: This sheet is not included in the Student Version of this guide. 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.

Measuring "sprout" length can be challenging because of their irregular shape. Here is an easy way to make a length measurement.

- 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.

Microsoft Excel: Entering Data and Creating Graphs

Teacher Hint: 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?

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 automatically.

- 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.

HOORAY!! YOU'RE FINISHED!

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