Scientific Method
Investigation of Plant Seed Germination

Learning Objectives
Building on the learning objectives from your lab syllabus, you will be expected to:
1. Be able to explain the process of the scientific method.
2. Use the scientific method to formulate a hypothesis and design an experiment investigating aspects of plant seed germination.
3. Be able to describe the process of plant seed germination and factors which may inhibit this process.
4. Be able to collect and present data
5. Be able to describe the parts of a scientific paper and write a scientific paper.

Pre-Lab Activity
Prior to this lab, you should:
1. Read Section 1.6 (Doing Biology) in your textbook (Freeman, 6th edition pages 9-13)
2. Review your 1107 lab handouts – Scientific Method Part 1 and Part 3
3. Review the UC Berkeley website http://undsci.berkeley.edu/article/intro_01 which has a good overview of the scientific method.
4. Review the Purdue University’s Online Writing Lab website which contains information on paraphrasing and plagiarism: https://owl.english.purdue.edu/owl/section/2/9/
5. Answer the following questions BEFORE lab:

   What are the major steps involved in the scientific method?
   _______________________________________________________________________________________
   _______________________________________________________________________________________
   _______________________________________________________________________________________
   _______________________________________________________________________________________

   What is a hypothesis?
   _______________________________________________________________________________________
   _______________________________________________________________________________________
   _______________________________________________________________________________________
   _______________________________________________________________________________________

   What are components of a good experimental design?
   _______________________________________________________________________________________
   _______________________________________________________________________________________
   _______________________________________________________________________________________

   Define the following terms:
   Independent variable ____________________________________________________________
   Dependent variable ____________________________________________________________
   Controlled variable ____________________________________________________________
Complete the following information for the given scenario: The more water you give plants the taller they will grow.

Hypothesis:
_____________________________________________________________________________________
_____________________________________________________________________________________

Control Group: _________________________________________________________________________
Experimental Group: ___________________________________________________________________
Independent Variable: ___________________________________________________________________
Dependent Variable: _____________________________________________________________________
Constants: _____________________________________________________________________________

What are the components of a scientific paper?
_____________________________________________________________________________________
_____________________________________________________________________________________
_____________________________________________________________________________________

What is plagiarism and how do you avoid it?
_____________________________________________________________________________________
_____________________________________________________________________________________
_____________________________________________________________________________________


Introduction

The scientific method is a logical process based on careful observation and experimentation. The information collected contributes to a comprehensive understanding of how the natural world works.

The scientific method is not always a strict step-by-step process, however there are certain components that are always found. The scientific method begins with an observation that leads to a question about the observed phenomena. Based on observations and evidence scientists generate a hypothesis, or a tentative explanation for the observed phenomena. Hypotheses are written as statements and they should always be testable. A good hypothesis offers only one explanation and leads to predictions (often written as an “if-then” statement). The predictions are tested using carefully designed experiments in which measurements are made and data is collected. Data collected from the experiments are analyzed and evaluated in respect to the original hypothesis statement, and conclusions are drawn. To contribute to the body of knowledge scientists report and share their findings.

Activity: Investigation of plant germination

Today you will use your knowledge of the scientific method to formulate a hypothesis and design an experiment. Specifically you will investigate aspects of plant seed germination.

Background to problem

Germination of typical seeds begins with the process of imbibing the seed (the passive uptake of water), continues with resumption of cellular metabolism and ends with the emergence of the radicle (root tip) from the seed coat. The processes of growth begins as germination ends, and these substantially enlarge the seedling.

This process is a critically important step in the life of a seed plant, because if germination occurs during unfavorable conditions the seedling is unlikely to survive. There are many possible cues that a seed can use to determine if conditions are favorable - temperature, light, loss of inhibitory compounds and, duration of warm or cold periods are some of the more common cues. You will be given the opportunity to examine one or more of the first three cues.

Experimental Design

Your instructor will inform you which chemical inhibitors or other possible germination cues are available. Determine which cue(s) your group will investigate. Before designing your experiment answer these important questions:

What will you be testing? ____________________________________________________________

What is your hypothesis and prediction? _____________________________________________
A well designed experiment should test only one factor (variable) at a time, with all other conditions being kept constant and the data collected should either support or reject the hypothesis.

As a group you should consider:
• What variables need to be constant?
• Do you need a control group?
• How many seeds per treatment/replications?
• What will you measure?

You will need to take into account that 100% germination is not guaranteed; there may be some individual variability in response to the cue; your instructor may ask for replicates and/or statistical analysis; there must be adequate liquid to hydrate the seeds; diffusion of gasses (oxygen especially) must not be excessively slowed.

**Materials - per group of two or four students**
- germination chambers (a.k.a. Petri dishes)
- water-proof marking pen
- radish (or other) seeds (Caution -if a red coating is present, it is a fungicide - limit contact & wash afterwards)
- deionized water
- inhibitors, etc. as specified by your instructor

After taking into account all the factors and materials available you should work with your group and design an experiment. Make note of all necessary details such that someone else could replicate your experiment exactly.

<table>
<thead>
<tr>
<th>Independent variable</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Dependent variable</td>
<td></td>
</tr>
<tr>
<td>Constants</td>
<td></td>
</tr>
<tr>
<td># of groups and comparisons</td>
<td></td>
</tr>
<tr>
<td># replicates</td>
<td></td>
</tr>
<tr>
<td># of seeds per chamber</td>
<td></td>
</tr>
<tr>
<td>Amount of water per chamber</td>
<td></td>
</tr>
<tr>
<td>Environment for duration of experiment</td>
<td></td>
</tr>
<tr>
<td>Length of experiment (#days)</td>
<td></td>
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</tbody>
</table>

**Set Up of Experiment**
Once you have carefully designed your experiment AND it has been approved by your instructor you will prepare your germination chambers.
- count out the required number of seeds and place each set in a germination chamber
- label the chamber (initials of investigators, lab section, treatment;)
- add measured fluids as required
- place closed chambers in specified area
• you may need to return to the lab to maintain your chambers (add water etc)
• you will need to return to the lab after two days (or as instructed) to collect data (assess germination)

Data collection/Results
Imbibition may increase size of the seedling and split the seed coat without germination occurring. To more accurately assess germination we will use actual growth of the radicle as an indication that germination has been successfully completed. For radish seeds, successful germination is considered a radicle of at least 4mm.

Figure 2: Measuring the length of the radicle. Be sure to use the metric units.

At the end of the experiment time determine how many seeds germinated in each group. Record the number of seeds with a radical of > 4mm and the number of seeds with a radical of < 4mm per treatment. Calculate percent germination per treatment.

\[
\% \text{ germination} = (\# \text{ germinated seeds/ total } \# \text{ seeds}) \times 100
\]

You do not need to report the radical lengths of each individual seed. You must show the % germination calculations in your final report.

Reporting your findings

An important aspect of the scientific method is reporting the findings, this is usually accomplished by publishing a scientific paper. Papers published in scientific journals are subject to peer-review. This means that to be accepted for publication, other scientists (the referees) must decide whether the research presented is important to the field and that the data and conclusions presented are well supported and valid.

The purpose of a scientific paper is to clearly communicate the research that was conducted. Scientific writing is usually presented in an impersonal, objective manner and reported in past tense. Although there are many variations there are certain components that are commonly found in a scientific data paper, you should have already reviewed these before lab. Generally the body of the paper begins with an Introduction, where the authors state the purpose of their research, provide necessary background information, and state their hypothesis. The procedure is described in the Materials and Methods, and the findings are presented in the Results section. In the Discussion, the authors interpret their findings, including evaluating their hypothesis and comparing their results to other research.

Science is a cooperative undertaking and while the purpose of a scientific paper is to share the information gathered in your own experiments the ideas are generally built upon existing theories and ideas. You will always find that scientific papers refer to previous research (cite references) throughout the paper and then conclude with a Literature Cited or References section, where the authors list all the references that were cited in the paper.
It is very important to develop skills in correctly citing and referencing in scientific papers. Although it may be done in other fields, scientific papers do not use direct quotations from sources. Everything should be written in your own words (paraphrased). A simple re-arrangement of the words in a sentence does not adequately paraphrase. You should think about the idea in the statement and how you would explain that idea in your own words.

Statement:
“Once they have dispersed from the parent plant, seeds may not germinate for a period of time. This condition is known as dormancy.” Freeman, Chapter 38 6th edition page 805

What does this mean to you? Paraphrase the above statement into your own words to explain the idea in the statement. __________________________________________________________________________
______________________________________________________________________________
______________________________________________________________________________
______________________________________________________________________________

Even though you are using your own words, you must acknowledge the source of all the information you use in a paper. Citations and referencing identify where an idea or information that is not your own came from (textbooks, journal articles, etc). Failure to properly paraphrase and/or acknowledge source material is plagiarism.

Your instructor may ask you to search for information to write your report. Any background information relevant to seed germination and papers that have investigated inhibitory factors are sources of information that you need to cite and reference in your paper. When selecting sources for information you must be sure that the source is appropriate. You can view the Reese Library guide on evaluating sources here: http://guides.augusta.edu/c.php?g=229989&p=1525507. For your report it is NOT appropriate to use a website as source of information. If you are asked to specifically use a peer-reviewed scientific paper then you will most likely need to use an academic search engine that allows you to find and access scientific papers. If you are not familiar with how to do this then you should seek help at the library.

There are many different ways that citing and references can be formatted. The purpose is firstly to acknowledge where the idea came from and secondly to permit the reader to trace the source of that idea. Citations can be presented in two ways in the body of the paper:
1) Information prominent citations - where the subject of the sentence is the information or fact and then the source is provided at the end of the sentence in brackets.
2) Author prominent citations - where the author names form the subject of the sentence, typically the sentence focuses on the research/viewpoint of the author cited.

Look at the examples provided below.
A: “Factors that initiate toxin production in cyanobacteria are not precisely known (Haider et al., 2003)”.
B: “According to Haider et al. (2003), factors that initiate toxin production in cyanobacteria are not precisely known. “

Which is an information prominent citation? ________________________________
Which is an author prominent citation? ________________________________
The reference list then provides all the information so that the reader can find the source paper. Note that even if you access a scientific article online a url address does not provide the reader with any important information. The reader needs to know: whose ideas you are using (authors); what the paper was about (title); and where and when it was published (Journal, year and publishing information). Every journal that publishes scientific papers has their own requirements for formatting styles for the in text citations and reference list.

Below are a few examples of styles for the reference list:

**APA:**

**Chicago:**

**MLA:**

**AMA:**

In each example above you can see that all the same information is presented just with different formatting. What are some of the differences you see?

________________________________________________________
________________________________________________________________________
________________________________________________________________________

These may seem like irrelevant details, however to submit a paper to a Journal you must follow their exact requirements. As a student you should practice this by ensuring you follow all the directions your instructor provides. Format your citations and references in a consistent format and in the exact way requested.
Post Lab Activity

Remember that your group will need to collect data before the next scheduled lab. You will have access to the lab only when there is no other lab is in session. Ensure you have coordinated with your group when and how the data will be collected and that you have a copy of the data.

You will need to submit a written report on this lab. Your instructor will inform you of the specific requirements for your report. You may be asked to complete a full written report including searching for and citing references. You may have to submit an individual or a group report.

Read the BIOL 1107 lab handout – Scientific Method Part 3 in preparation for writing this report.

The Writing Center at the University of North Carolina has an excellent webpage on scientific reports. It is a resource that you should also review in preparation for this writing assignment.
http://writingcenter.unc.edu/handouts/scientific-reports/