**Teacher Information: Timeline of Activities**

The following is a timeline of what will be happening with the plants as they grow and what students will be doing as they conduct their investigations. Please remember that biology is sometimes (often!) unpredictable, so this timeline is a ROUGH ESTIMATE. Trust your judgment and feel free to change your lessons and class time spent on the experiment according to what’s happening with the plants.

**Week 0  Friday (Day -3)  Introduction, Planting, and Vernalization**
- Introduce the PREP program and the *Arabidopsis* research project
- Divide students into pairs or small groups
- Plant wild-type and mutant seeds: 2 pots wild type, 2 pots mutant
- Put pots into refrigerator to ‘vernalize’ over the weekend
  This process convinces the seeds that they’ve just been through winter and Monday, when they are removed from the refrigerator, it will be springtime (‘vernal’ meaning spring)

**Week 1  Monday (Day 1)  End Vernalization and Plan Experiments**
- Remove plants from refrigerator
- Students plan experiments, including developing a question, forming a hypothesis, planning methods, and gathering materials.
- Lessons about seed structure and function and about what a plant needs to grow would fit well here

**Thursday or Friday (Days 4-5)  Initial Observations**
- Students may be able to observe the hypocotyl and cotyledons above ground
- Students may be able to observe and measure the cotyledons and hypocotyl
- **NOTE:** Each pot will have multiple plants. If there are more than 8-10 plants in a single pot, ask students to use tweezers to remove extras - this process is called thinning and prevents plants from getting overcrowded
- Lessons about accurate measuring and basic statistics (e.g. why is measuring more than one plant important? what is an average and why is it important?) would fit well here

**Week 2  Monday or Tuesday (Days 8-9)  Leaf Observations**
- Students may be able to observe the first ‘true’ leaves (as opposed to the cotyledons, which are embryonic leaves, a food storage tissue)
- The first leaves, *rosette leaves*, grow in a circle around the base of the plant
- Students may be able to observe and measure leaf size, shape, color, and number
- Lessons about leaf structure and function would fit well here
<table>
<thead>
<tr>
<th>Week 3</th>
<th>Thursday or Friday (Days 18-19)</th>
<th>Bolt Observations</th>
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<tbody>
<tr>
<td></td>
<td>Students may be able to observe the stem, or ‘bolt’, extending</td>
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<td></td>
<td>Students may be able to observe leaves on the stem, these are the cauline leaves</td>
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<td></td>
<td>Students may be able to measure bolt length, thickness, and color, and leaf size, shape, color, and number</td>
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<td></td>
<td>Lessons about stem structure and function would fit well here</td>
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<tr>
<th>Week 4</th>
<th>Thursday or Friday (Days 25-26)</th>
<th>Continued Observations</th>
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<tbody>
<tr>
<td></td>
<td>Students can continue to observe and measure bolt length, thickness, and color, and leaf size, shape, color, and number</td>
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<tr>
<th>Week 5</th>
<th>Thursday or Friday (Days 32-33)</th>
<th>Flower Observations</th>
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<tbody>
<tr>
<td></td>
<td>Students may be able to observe flowers growing and developing</td>
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<tr>
<td></td>
<td>Students may be able to observe and measure general flower characteristics like flower size, shape, color, and number as well as specific flower structures like petals, stamens, pistils, and ovaries</td>
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<td></td>
<td>Lessons about flower structure and function would fit well here</td>
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<tr>
<th>Week 6</th>
<th>Thursday or Friday (Days 39-40)</th>
<th>Seed Pod Observations</th>
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<tbody>
<tr>
<td></td>
<td>Students may be able to observe seed pods growing and developing</td>
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<tr>
<td></td>
<td>Students may be able to observe and measure seed pod number, size, shape, and color</td>
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<td>Lessons about plant reproduction would fit well here</td>
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<tr>
<th>Week 7</th>
<th>Monday to Friday (Days 43-47)</th>
<th>Complete Observations</th>
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<tbody>
<tr>
<td></td>
<td>Students should complete their observations and data collection</td>
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<td></td>
<td>Students can analyze their data using graphs, tables, statistics, etc. in preparation for their final presentations and formal research reports (these are to be submitted to the University of Arizona, the format for this is provided)</td>
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<tr>
<th>Week 8</th>
<th>Monday to Friday (Days 50-54)</th>
<th>Presentations and Research Reports</th>
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<tbody>
<tr>
<td></td>
<td>Students should finish preparing their final presentations and formal research reports</td>
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<tr>
<td></td>
<td>Students can present their work to their classmates and invited guests (parents, teachers, other students, scientists, etc.)</td>
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Teacher Information: Experimental Design

As outlined in the *Arabidopsis Research Project* section, the big idea is for students to determine what different plant genes do normally. To this end, students will grow and compare wild-type plants, with all functioning genes, and mutant plants, with a single non-functioning gene. Scientists have already compared the plants under normal conditions and have not seen any obvious abnormal phenotypes. It is up to your students to design and conduct creative experiments where they alter conditions in the plants’ environment to determine whether wild-type and mutant plants respond differently.

**An Example:** A group of students is interested in how UV light damages living organisms.
- The students develop a question:
  Are wild-type plants more resistant to damage by UV light than mutant plants?
- The students develop a hypothesis:
  If wild-type plants are more resistant to UV-light damage than mutant plants and we expose both plants to UV light, then the mutant plants will look more damaged. Evidence for this could include: brown leaves, slow growth, no flowers, etc.
- The students expose the plants to UV light for 1 minute as soon as first leaves start to grow.

**Control vs. Treatment:** In this experiment, there are two ‘treatments’ and two controls.
1) The wild-type plants are a control for the mutant plants. Growing the wild-type plants along side the mutant plants will make it easier to observe and measure any differences students see when comparing the wild type to the mutant. In essence, the mutant is intrinsically a ‘treatment’ and the wild type is intrinsically a control.
2) In our example, the environmental ‘treatment’ is UV light. The control would be no UV light exposure.

**Thus, the students need 4 pots of plants:**
- 1 wild type pot and 1 mutant pot that get no UV-light exposure
- 1 wild-type pot and 1 mutant pot that are exposed to UV light.

Students should examine not only whether the treatment affects each type of plant, but also whether the effect is different between wild-type and mutant plants.

For example, both wild-type and mutant plant leaves may turn brown after exposure to UV light, but do more or less of the mutant’s leaves turn brown when compared to the wild type?
Students can examine all manner of plant phenotypes during their investigations, from leaf size and shape to flower number and color to UV light sensitivity to ‘time to bolt’, meaning the amount of time after planting until the plants develop stems or bolts. On the following page is a list of phenotypes students can observe and measure, but encourage students to come up with their own ideas of plant characteristics they’re interested in examining.

NOTE: It is easiest to see how a mutant plant looks different when students compare the mutants to the wild types. Don’t just look at the mutants alone.
Phenotypes

Scientists have previously observed changes in these phenotypes in mutant plants. Your students may observe other phenotypes not listed below. Remember to always compare the mutant plants to the wild-type plants.

**Roots:** *Arabidopsis* roots are small and do not grow very deep.
- Root size/shape: Do the roots look thicker or thinner?
- Root length: Do the roots look shorter or longer?
- Twisting or wavy roots: The roots normally grow fairly straight - are they twisting or wavy?
- Abnormal root hairs: The roots have tiny hairs - are they missing? are they short or long?
- Misdirected root growth: The roots normally grow ‘towards’ gravity - are they misoriented?
- Root growth: Do the mutant's roots grow at the same rate as the wild type’s?

**Leaves:** *Arabidopsis* has two sets of leaves, the rosette leaves at the base of the plant and the cauline on the bolt.
- Leaf growth: Do the leaves grow at the same rate?
- Cotyledon size/shape: Are the cotyledons shaped the same? Are they the same size? Are there two?
- Hypocotyl size/shape: The hypocotyl is the part of the plant between the soil (or start of the root) and the cotyledons. Is the hypocotyl shorter or longer, thinner or thicker than wild-type?
- Cotyledon color/shade: Are the cotyledons the same shade (dark/light) and color (green or not)?
- Leaf size/shape: Are the leaves shaped the same? Are they the same size?
- Leaf number: Are there fewer or more rosette leaves? cauline leaves?
- Leaf color/shade: Are the leaves the same shade (dark/light) and color (green or not)?
- Leaf curling: Normal leaves curl down slightly - are the leaves curling up or both up and down?
- Stomata: Nail polish prints can be done to observe the shape, size, and number of stomata on the bottoms and tops of the leaves. Are these characteristics different in the mutant?
- Leaf location: Do the leaves grow at the right spots on the plant?

**Bolts:** Each *Arabidopsis* plant has a single bolt, or stem, covered by tiny ‘hairs’ called trichomes.
- Bolt size/shape: Does the bolt look thicker or thinner?
- Bolt length: Is the bolt shorter or longer?
- Trichome number: Trichomes can be observed with a hand lens or dissecting microscope - are there fewer or more trichomes?
- Trichome size/shape: Are the trichomes shaped normally? Are they larger or smaller?
- Bolt growth: Does the bolt start growing sooner or later? Does the bolt grow at the same rate?
**Flowers:** Each *Arabidopsis* plant grows several small, light yellow flowers.
- Flower number: Are there fewer or more flowers? Are there no flowers growing?
- Flower growth: Do the flowers start growing at the same time? Do they grow at the same rate?
- Flower location: Do the flowers grow at the right spot on the plant?
- Flower color/shade: Are the flowers the same shade (dark/light) and color?
- Petal size/shape: Are the petals shaped normally? Are they small or large?
- Petal number: Are there fewer or more petals on each flower? Are there no petals?
- Stigma shape/size: Is the stigma larger or smaller? Is it shaped normally? Is there no stigma?
- Stamen shape/size: Are the stamens larger or smaller? Are they shaped normally?
- Stamen number: Are there fewer or more stamens? Are there no stamens?
- Sepal size/shape: Are the sepals larger or smaller? Is it shaped normally?

![Flowers Diagram](image)

**Seeds:** The fertilized eggs, or ovules, will grow into small, green bean-shaped seed pods, called **siliques**, each containing 30-50 seeds.
- Seed pod size/shape: Are the seed pods shaped normally? Are they large or small?
- Seed pod number: Are there fewer or more seed pods?
- Seed pod location: Do the seed pods grow at the right spot on the plant?
- Seed pod color/shade: Are the seed pods the same shade (dark/light) and color (green or not)?
- Seed number/germination: Are there fewer or more seeds? Do they germinate at the same rate?

**General plant characteristics:** Some phenotypes are most obvious when you look at the plant as a whole.
- Dwarfism: Is the plant generally smaller or larger?
PRESENTATIONS and the FINAL REPORT

At the end of the Arabidopsis research unit ask students to present their research. This presentation should be accompanied by a visual research project board that takes one of two forms: Science Fair Project Board or Vee Map Project Board. Teachers are free to choose the type of presentation that students make, but giving students the choice is also a good option. Both formats are described below.

SCIENCE FAIR PRESENTATIONS Science Fair presentations typically take on the format of a tri-fold board (approximately 36 inches wide, 18 inches deep, and 48 inches high) divided into sections (see Figure 1). Common sections include:

• question or hypothesis section, to express the problem or question that the research will attempt to answer
• procedure section, to outline the materials and methods used in conducting the research
• data and results section, to summarize the research findings in both written and visual form
• conclusion section, to express whether or not the research answered the original question or hypothesis, as well as what the next step should be or the next questions to ask.

Students should also include a title on their project and as is often the case, a copy of the journal notes and a set up of the original experiment can be included. The Science Fair presentation should be attractive, and flow smoothly through the sections. It is important that each section be titled so that the viewer is not left guessing what section they are reading. For additional information, Janice VanCleave outlines how to set up and present a Science Fair presentation in her book A+ Projects in Biology (1993, pgs. 1-5).

Figure 1  Science Fair Project Components
VEE MAP PRESENTATIONS

Vee Maps typically take on the single flat board design and can be much smaller than the Science Fair presentation. A good size for a Vee Map might be 24 inches wide and 12 inches high (or larger). Like Science Fair boards, Vee Map boards are also divided into sections. Common sections include:

- focus question, which, like a hypothesis, is used to express the problem or question that the research will attempt to answer
- word list section, which includes words that are important to the understanding of the research
- concept map section, which shows pictorially how words and concepts from the research are linked together
- events section, which like a procedure section, delineates the steps followed in conducting the research
- data and analysis section, which summarizes the findings of the research in either pictorial or graphic form
- conclusion section, which like the Science Fair board is used to express whether or not the research answered the original question or hypothesis that was being asked, along with what the next step should be or the next questions to ask.

The suggested order of information on the Vee Map (see Figure 2) is taken from “Versatile Vee Maps,” which appeared in the January issue of The Science Teacher (Roehrig, et. al., 2001, pg. 28-31). It suggests that the focus question should be above the “V” as though it was a title. The word list and the concept map should be located on the left side of the “V,” and the conclusion and the data and analysis should be located on the right side of the “V.” The events section should be located directly under the “V” in the center of the the board. Teachers are free to arrange these sections as they see fit, but again a logical, smooth flowing arrangement will make it easy to read.

![Figure 2 Vee Map Components](image-url)
Either type of presentation can be quickly assessed by educators and scientists using any of a number of rubric styles. We have included a sample Vee Map rubric here. You can adjust or modify it to meet the needs of your classroom and students. Additionally, point values can be changed according to your standard point scale.

**FINAL WRITTEN REPORT**

Ask students to write and submit a formal lab report. These reports will be compiled into a reference booklet of students reports that will be provided to other students and scientists involved with the project. Please require that final reports be no more than two pages and follow the enclosed format. (Please ask students to write legibly if they are hand writing on the form.) The form follows a standard research outline and students should fill in each section using complete sentences and a strong third person voice. The sections included on the form are:

- question or hypothesis section, where students clarify the problem or question the research will attempt to answer
- procedure section, where students outline/summarize the materials and methods used to conduct the research
- data section, which students will use to present their graphs and tables
- results section, where students summarize the information presented in their data section
- conclusion section, where students explain whether or not the research answered the original question or hypothesis that was being asked. Ask students to include ideas for future research and questions that arise from completing the current research.

Please remind students to be concise, as they only have two pages to complete their reports.
VEE MAP RUBRIC

Group members’ names:

Word List
- 4: Thorough list of relevant key words encompassing the topic
- 3: Relevant key words describing topic
- 2: Associated words listed, but some key words missing
- 1: Limited list of associated key words
- 0: Sparse list or no attempt made to complete the section

Concept Map
- 4: Words are linked correctly and concept map addresses laboratory topic. Almost all words in the word list are used, and there are levels and cross-links in the concept map
- 3: Most words from the word list are used and linked accurately. Concept map addresses the laboratory topic, and some cross-links and levels exist
- 2: Some words are used from the word list. The concept map needs additional clarification. There may or may not be cross-links and levels
- 1: The concept map does not directly address the laboratory topic. Some words are used from the word list, and there are levels with few or no cross-links
- 0: Limited concept map with few words, or no attempt was made to complete the section

Events
- 4: The description or illustration is accurate, complete, and addresses the focus question
- 3: The description or illustration aims to answer the focus question. Clear and concise, but a few additional details could be added
- 2: The description or illustration aims to answer the focus question. Additional information is needed about the event
- 1: A limited description or illustration is presented; focus question may or may not be addressed. Additional information is needed
- 0: The description or illustration does not align with the focus question, it is incomplete, or no attempt was made to complete the section

Data and Analysis
- 4: Well organized data table, includes all relevant data. Data is accurate, units are present, and the analysis is correct and complete
- 3: The data table is complete. Data is accurate and the analysis is complete
- 2: Data table is complete, but additional data should have been collected and recorded. The analysis of data is acceptable and may or may not relate to the focus question
- 1: Minimal data table, lacking some relevant data. Data may or may not be accurate. Analysis is incomplete or inappropriate to answer the focus question
- 0: Minimal data table, incomplete analysis, or several problems with data collection and analysis, or no attempt was made to complete the section

Conclusion
- 4: A thorough conclusion that comes from the data, an understanding of the topic is advanced, the focus question is addressed in a comprehensive manner, there is a connection to the concepts initially indicated, and new study questions are posed
- 3: The conclusion adequately addresses the focus question, and the conclusion comes from the data and connects to previously listed concepts. New study questions may be posed
- 2: The conclusion addresses the focus question. The conclusion is limited, it is drawn from the data, and some previous concepts may be listed
- 1: The conclusion is limited and may or may not address the focus question. The conclusion may or may not come from the data, and it may or may not address the previous concepts
- 0: A limited conclusion that does not emerge from the data, or no attempt was made to compete the section

Total number of points
PROJECT TITLE:  

AUTHORS:  

HYPOTHESIS OR QUESTION:  

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PROCEDURE  

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DATA