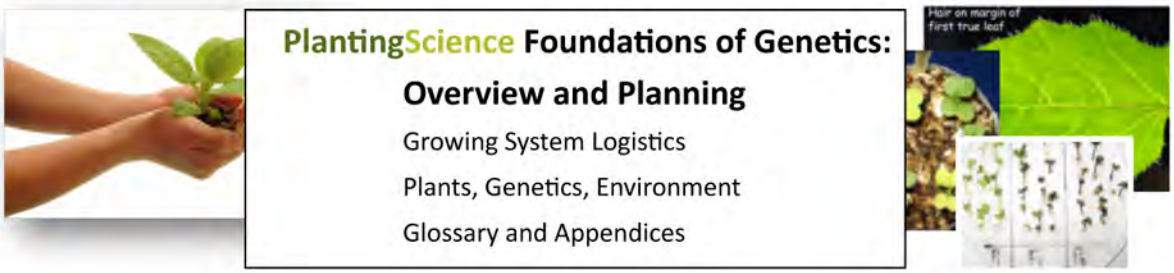
PlantingScience Foundations of Genetics: Traits, Variation, and Environment in Rapid Cycling *Brassica rapa*

Teacher's Guide

Table of Contents

Each section is available for download in pdf format from www.PlantingScience.org.



Targeted grade levels: 9-12, for integration in courses such as Basic Biology, Botany, Genetics

Module length: 6 -7 weeks (possibilities for longer extensions)

Prior student background: None required. Module extensions can be used with students or classes who have more background.

Abstract: Designed as a whole-class experiment, students work in teams to grow a selected strain of *Brassica rapa* plants from seed to seed, and monitor plant traits as they develop over the course of a life cycle. Observations and measurements are made, pooled with data from other teams, and analyzed for discrete traits (the result of one gene), and continuous or quantitative traits (the result of multiple genes). Plants are grown in populations large enough so the variation of traits within a population can be documented and analyzed. Such variation within populations is foundational to understanding selection and evolution. Plants will also be grown in two environments to illustrate the principle that a phenotype is the result of an organism's genotype interacting with its environment. Students communicate with scientist mentors online to discuss their experiment.

Concepts

- Plants are living, reproducing organisms that live in and are influenced by the environment.
- Inheritance of genes occurs via the life cycle of an organism through successful reproduction of offspring.
- An organism exists as an expression of its inherited genes interacting in an environmental context (*Phenotype = Genotype X Environment*).
- Plants vary in their phenotypes (traits), and we can observe, measure and analyze this variation by studying populations of plants.
- Science is an active process of inquiry, investigation, and communication.

Collaboration and Support: This module was developed for the PlantingScience program of the Botanical Society of America in collaboration with Paul Williams, Amber R. Smith, and the Wisconsin Fast Plants® Program at the University of Wisconsin-Madison. All material reproduced here from the Wisconsin Fast Plants® Program is used with generous permission. Additional funding has been provided by the National Science Foundation, and the Monsanto Foundation.

Module Information and Use

A Word to Teachers

We provide tools and instructions for *Brassica* Genetics on the PlantingScience website to help you develop your class investigation using the model organism, *Brassica rapa*.

The seed line(s) have been specially cultivated to investigate certain discrete traits and quantitative traits. These traits are described in detail on page 9 of the Overview and Planning section, and again in the Traits section.

Student activities described in the Plants, Genetics and Environment section include some suggested traits to investigate, writing prompts, and discussion points. Please augment these to suit your own needs. A number of these pages are formatted for easy use as student handouts.

Please remember to have students communicate with mentors prior, during and at the conclusion of the module. Your direct communication with mentors is also immensely helpful – see Teacher-Mentor Discussion Forum on your personal PlantingScience web page.

Sections of Module

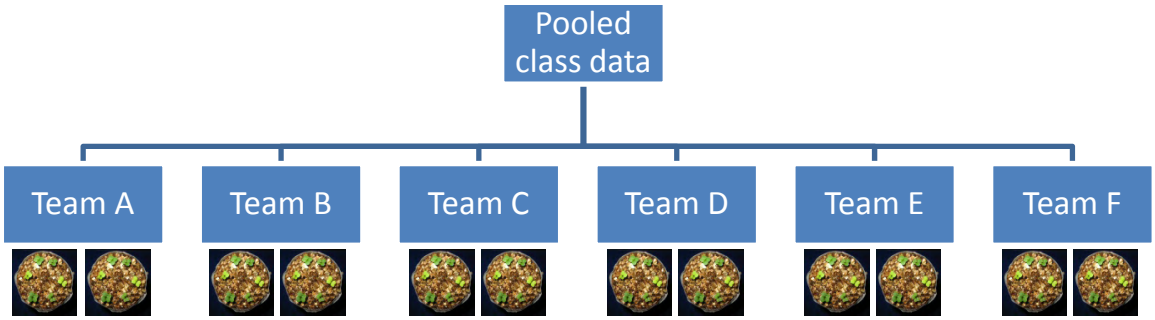
Available for download in pdf format from www.PlantingScience.org

The following sections for the *Brassica* Genetics module are available on the PlantingScience website in pdf format. These sections will be referred to throughout the module text.

- Table of Contents
- Overview and Planning (this section)
- Growing System Logistics
- Plant, Genetics, and Environment
- Glossary and Appendices

Module Design and Learning Goals

Guided Inquiry and Pooling Class Data: Designed as an all-class experiment, living plants are used in a guided hands-on inquiry to explore the foundations of genetics. The planting and growing conditions of the plants will be guided for the students, as will many of the activities. This module depends on pooling data from all teams to analyze as a class.



Student Teams: Students will be grouped into small teams. Activities such as planting, watering, observing and collecting data can be conducted in teams. Each team will be assigned one scientist mentor to communicate with on the PlantingScience website. Please allow time for this important and rewarding communication. The data from student teams will be pooled with other teams within a class for analyzing variation within the population of class plants.

Learning Goals

Students will:

1. Plant seeds and tend plants through a life cycle;
2. List and describe the major steps in a plant life cycle;
3. Identify, observe and record traits of plants as they grow and develop;
4. Share and analyze data among classmates;
5. Understand that plants vary in their phenotype (traits) within a population;
6. Explain how organisms are influenced by the environment;
7. Understand that inheritance of genes occurs via the life cycle of an organism through successful reproduction of offspring;
8. Understand that an organism's phenotype is an expression of its genotype interacting with the environment (P = G X E);
9. Understand the difference between discrete and continuous traits;
10. Understand that phenotypic variation enables plants to be more successful in different growing conditions and therefore produce more offspring.
11. Communicate with scientist mentors about their class experiment;
12. Experience science as an investigative process.

Materials

Overall cost:

- Approximately $80-$100 for one class to grow F2 generation only.
- If more seed lines are grown, additional light boxes needed – approximately $25 each.
- These figures assume no cost for plastic bottles – that recycled bottles will be used.

Brassica rapa seed – PlantingScience will supply teachers with F2 seed

From: Carolina Biological http://www.carolina.com/

- F2 generation – **required – PlantingScience supplies**
  - This is the main generation the entire class grows.
  - Minimum of 100 seeds per class is required.
  - Seeds come in packets of 250 for $31.50
  - Carolina description and stock number: "F2 non-purple stem, yellow-green leaf": #158888

- F1 generation – **optional**
  - This is an option if the teacher wants to grow a population of plants up to show students the variation (or lack thereof) in traits of the F1 generation.
  - Seeds come in packets of 50 or 200. Recommend ordering packet of 50 for $11.25
  - Carolina description and stock number: "F1 non-purple stem, yellow-green leaf": #158890

- Parent lines, P1 and P2 – **optional**
  - These **2** lines are an option if the teacher wants to grow populations of these lines to show students the characteristics of each parent line. These 2 parent lines were those originally crossed.
  - Seeds come in packets of 50 or 200. Recommend ordering packet of 50 each for $11.25 each (total $22.50)
  - Carolina description and stock number:
    - **P1** – "Hairless, non-purple stem": #158812
    - **P2** – "Yellow-green leaf": #158819

Materials per class

- *Brassica rapa* seeds – PlantingScience will provide F2 seeds
  - F2 generation **required** (100 seeds per class)
  - F1 generation **optional**
  - Parental lines (2), P1 and P2 **optional**

- Light System*
  - Fluorescent light banks, **OR**
  - Screw-in fluorescent bulb in a constructed light box*

- Planting System*
  - Bottle system made from plastic drinking bottles (12 ten-oz bottles)*, **OR**
  - Quad cell system[§]

- Planting Medium*
  - Seedling starter soil, **AND**
  - Vermiculite

- Fertilizer*
  - Osmocote pellets

- Water and watering vessel*

- Dried bees to make bee sticks[§] * (Stock #158985)

---

* - See detailed instructions and materials list in *Growing System Logistics* section

[§] - Available from Carolina Biological Supply

Practical Considerations

You'll Also Need:

- **Lab equipment and tools.**
  - Wet lab or table space that can get dirty
  - Sharpies, colored tape for labeling
  - Magnifying glasses and/or dissecting scopes
  - Measuring tools – rulers, calipers, etc. (for measuring height of plants, length and width of seeds, leaves, stems and other structures)

- **Access to computers.**
  - Necessary for online communication with scientist mentors
  - Helpful for entering data into databases (such as Microsoft Excel), pooling data, and analyzing data for patterns

- **Time for mentor dialogues.**
  - Scheduled time for students to communicate with mentors online
  - Time for teachers to monitor dialogues
  - Time for teachers to assess and award credit for dialogue with mentors

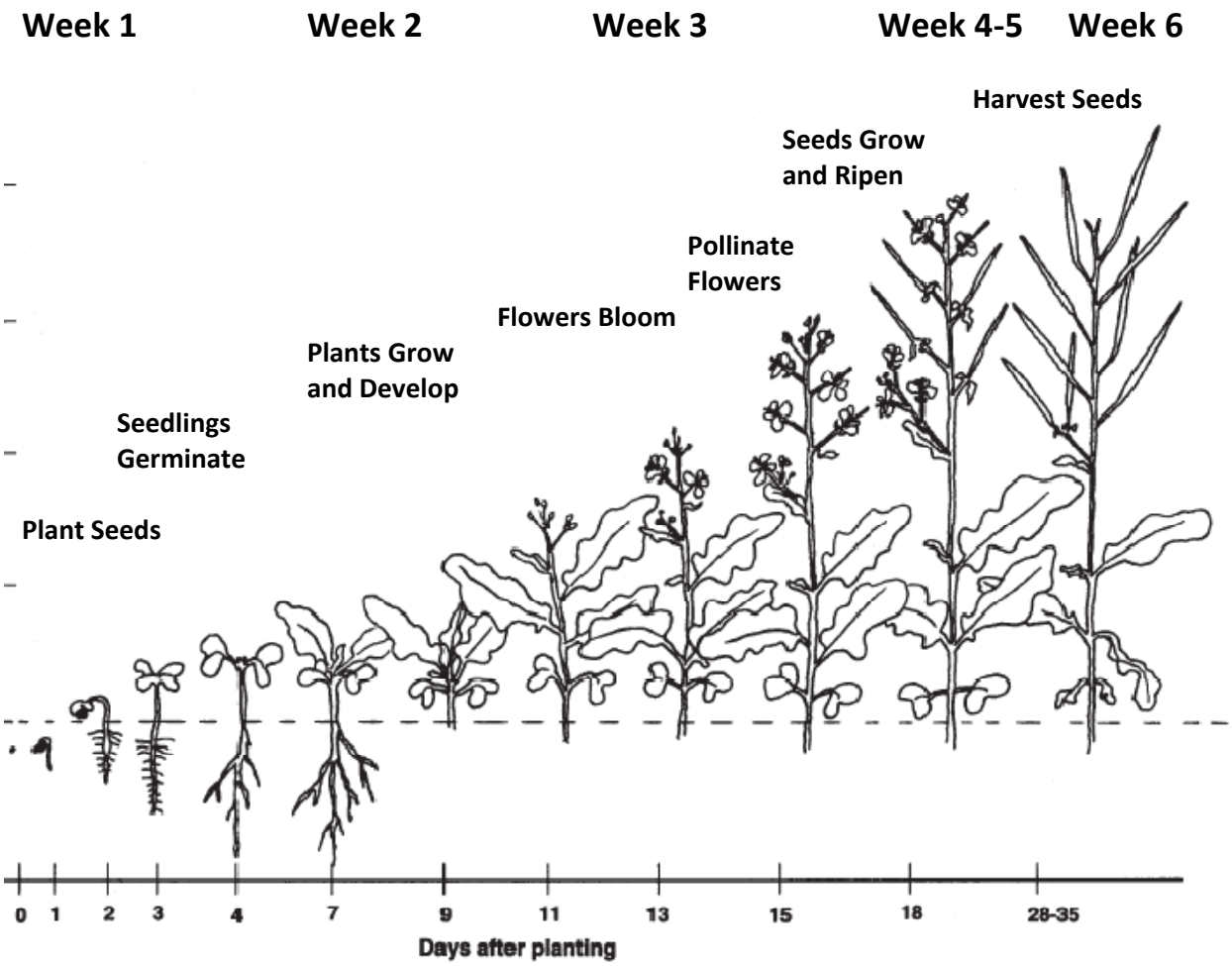
- **Lab journals for students.**
  - Important for ongoing record of observations, data collection, sketches, notes, thoughts and ideas

General Timeline

Days after planting	Life Cycle Stage	Learning Goals	Suggested Activities	Guiding Questions
Preparation		1,6, 11, 12	Create the Growing System (pp. 14-22) Experimental Design: Use 2 nutrition levels (pp. 9-10) The Environment (p. 13) Start Lab Notebooks (p. 25) Register Online and Introductions to Mentors	What does a plant need to grow? Why is important to have a "control" in an experiment? How will I keep track of the details of the experiment? Who is my mentor, and how will I communicate?
0	Dormancy – Seed	1,2,3,4,5, 6,7,9, 11, 12	What is a Trait? Nature or Nurture? (p. 27) Observe Seed Traits (pp. 29-30) What is a Population? (p. 31) Communicate with Mentors Online	Are seeds living or dead? What is a seed made up of? Are all seeds the same? How do we describe traits? How do we compare traits? What is a population?
0 – 3	Germination	1,2,3,4,5, 6, 11, 12	Plant the Seeds (pp. 19-22) Germinate Seeds for Observation (pp. 29-30) Communicate with Mentors Online	What environment do *Brassica* seeds need to germinate? How do plants contribute to environmental conditions? How does a seed begin to grow? Where does the new plant get the energy to grow?
3 – 10	Vegetative Growth and Development	1,2,3,4,5, 6,8,9,10, 11, 12	Observe, Measure, Record (pp. 25-28) Record *Discrete Traits* (pp. 33-35) Record *QuantitativeTraits* (pp. 36-42) Pool and Analyze Class Data (pp. 25-26) Compare plants in different environments (Phenotype = Genotype X Environment) (p. 43) Communicate with Mentors Online	What is a phenotype? Are all the plants in a population identical? What is variation? Do traits vary over time and development? Are traits affected by environment? What is the difference between discrete and continuous traits? What does average mean? Are there advantages for a plant to have certain traits? Does that differ in different environments?

Days after planting	Life Cycle Stage	Learning Goals	Activities	Guiding Questions
11 – 18	Flowering	1,2,3,4,5, 7,8, 10, 11, 12	Observe Flower Development (p. 37) Review Flower Anatomy and Reproduction (pp. 44-49) (Meiosis – creation of gametes) Communicate with Mentors Online	What's in a flower? What are the functions of flowers and flower structures? What does a flower turn into? Do all plants flower? Or flower at the same time? Why might flowering differ among plants?
11 – 18	Pollination	1,2,3,4,5, 6,7,8, 10, 11, 12	Make Bee Sticks (pp. 44-45) Pollinate flowers (pp. 44-49) (Extensions: possibly select plants to pollinate – App. B and C) (Fertilization – union of gametes) Communicate with Mentors Online	What are the benefits of cross pollination? Why is the bee a good pollinator for Brassica? Are there certain flowers that might be more attractive to a bee? Is pollination the same thing as fertilization? When is a Brassica ovule fertilized? Can plants that don't flower, or don't pollinate, produce seeds?
18 – 35	Seed Development	1,2,3,4,5, 6,7,8, 10, 11, 12	Observe development of: pod (silique), seed, seed coat, endosperm (p. 50) Count seeds per pod, and per plant (p. 50) Analyze data and compare with other traits (pp. 36-39) Discussion of generations (seed vs. parent) Communicate with Mentors Online	Fertilized and ripened ovules become what? Ripened ovaries become what? Is there a relationship between plants with certain traits and the number of seeds produced? Is there a relationship between plants grown in high or low nutrients and the number of seeds produced?
35 – 42	Senescence	1,2,3,4,5, 6,7,8, 10, 11, 12	Discussion of dying process Collection of seeds (p. 50) Communicate with Mentors Online	What is the difference between annual and perennial plant? What is dormancy?

General Timeline



Additional resources:

Growth, Development and Reproduction Booklet. Wisconsin Fast Plants.
http://www.fastplants.org/pdf/activities/WFP_growth-development-06web.pdf

Fast Plants Life Cycle (with descriptions of each stage and time lapse video)**:**
http://www.fastplants.org/intro.lifecycle.php

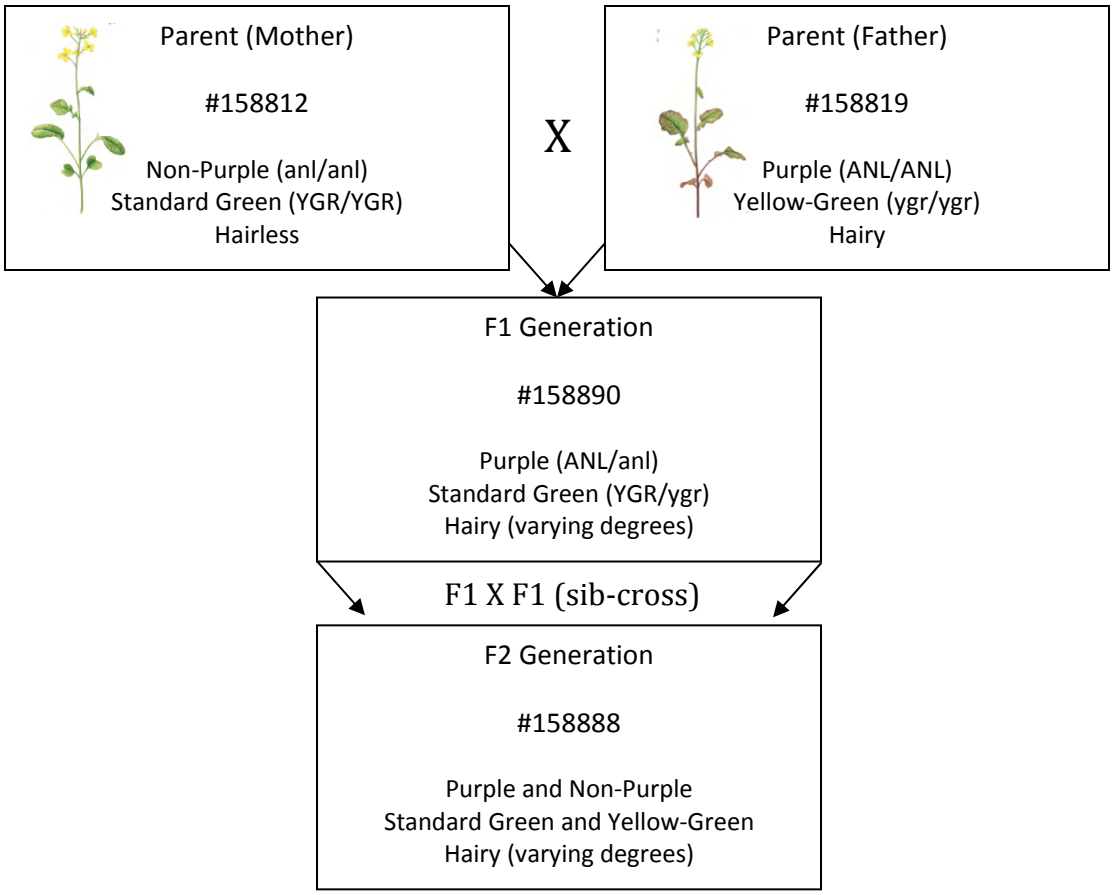
Experimental Design

Seed Stock

We use a unique strain of *Brassica rapa* specifically cultivated for quick progression through its life cycle, *Rapid Cycling Brassica*. We have drawn on the decades of innovative research by Professor Paul Williams at University of Madison – Wisconsin and Wisconsin Fast Plants in developing strains of *Rapid Cycling Brassica* for use in educational settings.

This module is designed for use with an F2 generation of seed stock, as illustrated below. This F2 generation (designated in the bottom box below) was created by the crosses from parent lines as shown below. Seed stock from each individual line is available through Carolina Biological Supply http://www.carolina.com/ . The Carolina seed stock number relevant to each line are shown the boxes below. The traits specific to these lines include:

- **Discrete Trait for Purple / Lack of Purple.** Anthocyanin is a purple pigment, especially visible on the stems, hypocotyls, under cotyledons, and at leaf tips. A single gene, the anthocyaninless gene (anl), in Wisconsin Fast Plants® regulates whether or not anthocyanin will be expressed.
- **Discrete Trait for Standard Green / Yellow Green.** The yellow-green gene (ygr) in Wisconsin Fast Plants® determines whether the leaves will be standard green or yellow-green in color.
- **Quantitative Trait for Hairiness (Trichomes).** Multiple genes work in concert to regulate the number of small hairs, or trichomes, on leaves and stems. There are varying degrees of hairiness.



Experimental Design

Population Size of F2 Generation (Seed Stock #158888):

We recommend students grow the F2 seed stock, creating a large enough population of plants within the class to:

- Have every student directly engage in growing and tending plants, observing and measuring traits, pollinating flowers, and harvesting seeds
- Analyze variation in discrete and quantitative traits (good to have at least 30 plants in each treatments)

We recommend a total of 36 plants in each of two treatments (see below), **for a total of at least 72 plants per class.**

Carolina Biological Supply makes this stock available in packets of 250 seeds (#15888).

Environmental Conditions and Treatment Variables:

In the study of genetics and evolution, it is critical to understand that *selection occurs upon the phenotypes of organisms*, and that *phenotypes are influenced by the environment*. Two organisms of the same genotype can have different phenotypes because of environmental influences. Therefore, we manipulate one variable in the environment to test differences in plants between the two treatments.

- **Constant conditions:**
  - Light (same quantity and quality for all plants)
  - Water (equal amounts of water for all plants)
  - Temperature (same temperature for all plants)
- **Treatment variable (independent variable):**
  - Nutrition levels (half plants have adequate nutrition, half plants have low nutrition)
- **Dependent variables:**
  - Could include, but not be limited to: height, number of leaves, size of leaves, number of flowers, number of pods, number of seeds, color, number of trichomes (hairiness), days to flowering

Examples of Questions for Inquiry (not an exhaustive list – be creative!):

- What traits are influenced by genetics, environment, and/or both?
- If I know parental traits, can I predict in what proportions discrete traits (purple / lack of purple, yellow-green / standard green) will be expressed in the F2 generation? How do the actual proportions compare with my predictions (from Punnett Squares)?
- Can I predict how continuous traits will vary?
- Is a specific trait a discrete or continuous trait?
- How does nutrient environment influence specific phenotypes?
- Can I predict each stage of the plant life cycle?
- Are there certain traits that help a plant be more successful (produce more viable seeds)?

Suggested Lesson and Activity Planner

	Monday	Tuesday	Wednesday	Thursday	Friday
Week 1 **Planting and Germination**	-Prepare and organize growing and light systems -Register online and introductions to mentors	-As a class, organize experimental design (2 nutrient levels) -Explore the nature of seeds -Plant seeds with 2 nutrient levels	-Discuss requirements for a plant to grow (environment and genes) -Explore concept of population -Make predictions of how plants will grow		***Scientists & students explore requirements for a plant to grow, and concept of population***
Week 2 **Growth and Development**	-Identify stages of plant life cycle -Describe traits and understand *phenotype* -Note how traits vary and develop over time	-Observe plant traits, measure, describe, draw -Record and analyze data -Understand *discrete traits* -Understand *continuous traits*	-Explore variation of traits within population(s) -Compare traits in high and low environments - Phenotype = Genotype X Environment		***Scientists & students explore life cycle stages, traits, and phenotypic variation.*** ***Upload data collected on traits to share with scientists.***
Week 3 **Flowering and Pollination**	-Observe development of flowers -Review flower anatomy and reproduction	-Distinguish btw pollination and fertilization -Observe pollen -Make pollination bee sticks	-Conduct pollination activities -Make predictions about seed development -Continue recording and analyzing trait data		***Scientists and students explore plant reproduction: structures, function, pollination, inheritance. Relate these to everyday life: food, textiles, etc.***
Continued on next page ….					

Teams are encouraged to post online 2-3 times per week. This icon indicates especially important opportunities for Team Research Blogging and talking with their online mentors. Teams can blog more often from school or home.

	Monday	Tuesday	Wednesday	Thursday	Friday
…Continued from previous page					
Week 4 **Flowers, Fruits, and Seeds**	-Complete pollination activities -Observe silique (pod) development	-Identify factors that might affect seed production and viability -Estimate and record seed production in plants	-Organize and analyze data		***Scientists and students share observations of seed production. Why are some plants producing more seeds than others?***
Week 5 **Seed Production**	-Let seeds dry -Discussion of generations (seed vs. parent) -Explore fruit and seed structures	-Estimate and record seed numbers in pods -Discuss world food crops and seeds as energy for plants and animals	-Pool and analyze class data -Analyze data from plants for patterns of discrete traits and continuous traits		***Students – upload data and reports for scientists.*** ***Scientists – share advice in analyzing data and recognizing patterns.***
Week 6 **Senescence, Seed Collection and Reporting**	-Discuss differences between annual and perennial plants -Collect seeds in pods	-Continue to pool and analyze class data -Discuss role of inheritance and environment in phenotype -Discuss selection and evolution	-Conclusions and reports -Clean lab and store equipment and seeds Assessment on: -Patterns of variation -Patterns of inheritance		***Students – upload data and reports for scientists.*** ***Scientists – share advice in analyzing data and recognizing patterns.***

Teams are encouraged to post online 2-3 times per week. This icon indicates especially important opportunities for Team Research Blogging and talking with their online mentors. Teams can blog more often from school or home.