Teacher’s Guide

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Allele: Alternate forms of a gene that produce different phenotypes.

Anthocyanin: Purple pigments produced in plants that protect plants from light damage by absorbing light in the blue-green and UV spectra. Anthocyanins can be found in any plant tissue and examples include the purple in grapes and red color of leaves in the fall.

Carpel: The female part of the flower that is usually made up of the stigma, style, and ovary.

Cotyledon: Leaves that are formed during embryogenesis and will provide food to the germinating seedling until the first true leaves expand and begin photosynthesizing.

Development: Describes the process of a change in form or function in an organism.

Discrete phenotypes are the result of one gene, and are often definitive traits, such as yellow vs. green color, or smooth vs. wrinkled seed. They can often be scored as either one form or the other, or the presence or absence of a trait. Discrete traits conform to Mendelian patterns of segregation.

Dormancy: a time in which an organism’s growth and development is stopped and metabolic activity is reduced to save energy.

Double Fertilization: The process that is unique to flowering plants and results in a zygote and endosperm. One sperm cell unites with the egg cell to create the zygote while the other sperm cell unites with two polar nuclei cells to form the endosperm.

Endosperm: a nutrient rich tissue formed during fertilization that provides energy to the developing embryo. This tissue also provides the majority of the calories for all of the humans in the world.

Environment: All of the biotic, chemical, and physical components that surround an object.

Evolution: A change in the characteristics (phenotypes) of a population over time.

First true leaf: The first leaf that is produced after germination from the shoot meristem.

Generation: Successive stages in a lineage. For example, three different generations include grandparents, parents, and children.

Genes: Genetic material that contains the information required to create an organism.

Genotype: All of the alleles that make up an individual.
**Germination:** The process during which a dry seed takes up water and elongates its roots and shoots to emerge from the seed coat.

**Growth:** An increase in size over time.

**Heritability:** The proportion of phenotypic variation that is due to genetic variation and thus can be inherited in the next generation.

**Hypocotyl:** A stem-like structure between the cotyledon and root.

**Inheritance:** The passing of genetic material from the parental generation to the offspring.

**Law of independent assortment:** Alleles of unlinked genes are independently sorted from one another during gamete formation. This means that alleles not physically close to one another on the chromosome will be inherited independently of one another.

**Law of segregation:** Each allele in a pair is separated into a different gamete during meiosis to ensure that each gamete only receives one copy.

**Life cycle:** The progression from embryo to juvenile to adult (reproductive) to death. The cycle continues on with the offspring created during the adult phase.

**Meiosis:** The process that results in the formation of gametes. During meiosis the genome undergoes two divisions resulting in gametes with half the number of chromosomes as found in the original cell.

**Nectary:** A gland that produces a sugary liquid that is used to attract pollinators to plants.

**Ovary:** The bottom part of the carpel that contains the ovules.

**Ovule:** The structure that contains the egg cell (female gametophyte) in seed plants. After fertilization and development, the mature ovule will become a seed.

**Petal:** The part of the flower that is often brightly colored or uniquely shaped. Petals are used to help attract pollinators.

**Phenotype:** The observable traits of an organism that are determined by the expression of an individual’s genes and the influence of the environment.

**Pollen grain:** The structure that contains the male gametophyte (sperm).

**Pollination:** The act of pollen movement from the anther to the stigma. Pollination may occur by moving pollen from one plant to another (cross-pollination) or by moving pollen to the stigma on the same plant (self-pollination).

**Population:** A group of interbreeding individuals that inhabit the same area. In the case of asexual organisms a population is a group of individuals in the same area.

**Protocol:** A standardized set of procedures or methods used to conduct a scientific experiment.
**Quantitative phenotype:** Phenotypes displaying continuous variation. Quantitative phenotypes are the result of the interaction of many genes. With many genes involved, there are typically many more “options” for expression of that trait rather than just one or two forms. So, the varied expression of all of these genes leads to greater variation of continuous trait phenotypes compared to discrete trait phenotypes.

**Reproduction:** The process by which new organisms are created. The process may be sexual or asexual.

**Root:** The plant organ that is responsible for taking up water and minerals from the soil. Roots also anchor and stabilize the plant.

**Seed coat:** The outer layer of the seed that helps to protect the plant. The seed coat tissue is from the ovule and thus has the genetic makeup of the mother plant.

**Selection:** The process of choosing some individuals from a population that will mate and produce offspring. During natural selection individuals that are most well adapted to the environment are able to produce more offspring than those individuals that are less well adapted. The characteristics of the population shift to reflect the traits of the adapted individuals. However, artificial selection favors individuals with traits that are useful or favored by the human that is doing the selecting.

**Sepal:** A leaf-like structure that is often the outermost part of the flower. Sepals often enclose the other floral structures prior to blooming.

**Self-incompatibility:** A mechanism that prevents self-fertilization by stopping pollen germination, pollen tube growth, fertilization, or embryo development. The result is that no viable seeds are produced. This mechanism promotes outcrossing and genetic diversity.

**Silique:** The pod-like structure that contains the seeds of plants in the *Brassicaceae* family.

**Stamen:** The male reproductive structure in a flower that is usually composed of a filament and anther.

**Stigma:** The area on the carpel that receives the pollen.

**Trichome:** Small hair-like structures that grow out from the epidermal tissue layer.

**Variation:** The differences between individuals in a population.
Appendix A

Alternative Method: Two Nutrient Solutions (Two Environmental Conditions)

Overview

The experiment will use two different nutrient solutions so that plants in two environmental conditions can be compared. The nutrient solutions are designated in milligrams of soluble nitrogen, N, per liter of water (parts per million, or ppm). All other nutrients in the Jack’s fertilizer will be in proportion to the level of nitrogen in the water and nutrient solution. One level of nutrition will be 100 mg N/liter of water (100 ppm). The second level of nutrition will be 25 mg N/liter of water (25 ppm). The two levels will be mixed from one stock supply mixed in a 2-liter bottle.

Materials

- Two 20 oz plastic bottles
- One 2-liter plastic bottle
- Fertilizer – Recommended fertilizer is Jack’s(formerly called Peters) 20-20-20,N-P-K+minor elements
- “Soft” water (i.e., low calcium) – if you are in an area with “hard” water, use de-ionized, distilled, or reverse-osmosis (RO) water

Procedure

1. Strip the label off the 2-liter bottle and set aside.
2. Measure water into the 20 oz. bottles and mark them every 100 ml as shown in the photo.
3. Nearly fill the 2-liter bottle with water.
4. Add 2 grams of Jack’s fertilizer (one 1.5 ml microcentrifuge tube full = ~1 gram) to the water in the 2-liter bottle.
5. You now have 2 liters of a 2X “stock solution” of 200 ppm N in the 2-liter soda bottle. Store the bottle in the dark or wrap it in foil to avoid algal growth in the solution.
6. Make the 100 ppm N nutrient solution in one of the 20 oz. bottles by diluting the 200 ppm “stock solution” by half. **Label bottle as 100 ppm N.**
7. Make the 25 ppm N nutrient solution in the other of the 20 oz. bottles by diluting the 200 ppm “stock solution” to 1:8. **Label bottle as 25 ppm N.**
8. Store these nutrient solutions in the dark as well.
Appendix B

Extension: Mendelian Genetics

An essential part of the life cycle is the passing of traits from one generation to the next. *B. rapa* is an excellent system to study inheritance due to its rapid generation time and floral structures that are large enough for beginning students to manipulate. The seed stock provided for the Life Cycle Investigation contains a discrete trait that is easy to identify and thus easy to trace from generation to generation. The trait is the presence or absence of a purple pigment called anthocyanin. Plants with at least one dominant anthocyanin allele (\(-/ANL\) or \(ANL/ANL\)) will produce anthocyanin which may appear on the hypocotyl, stem, leaf tips, and hydathodes. Plants with a recessive genotype for this gene (\(anl/anl\)) will not produce anthocyanin and thus they appear totally green.

*Note*: The anthocyanin phenotype will segregate as a single gene according to Mendelian ratios if plants are scored for presence or absence of anthocyanin. There are other genes associated with the phenotype that will affect the intensity of the anthocyanin. In this way anthocyanin is also a quantitative phenotype. The idea that a phenotype can be discrete and quantitative may be a good discussion topic for some students. If you anticipate this to be confusing there is no need to present the phenotype as being quantitative.

To provide a real life example of inheritance in action the students can make crosses between two individual plants. Students will need to use their knowledge of phenotypes, genotypes, and segregation to predict the phenotype(s) that will appear in the next generation. Given that the presence of anthocyanin is caused by a single dominant allele the students may need to do multiple crosses with the purple plants to determine the genotypes of the parents.

Possible cross combinations:

<table>
<thead>
<tr>
<th>Parent Phenotype</th>
<th>Parent Genotype</th>
<th>Offspring</th>
<th>Offspring Genotypes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purple x Purple</td>
<td>ANL/ANL x ANL/ANL</td>
<td>100% Purple</td>
<td>100% ANL/ANL</td>
</tr>
<tr>
<td>Purple x Purple</td>
<td>ANL/anl x ANL/ANL</td>
<td>100% Purple</td>
<td>50% ANL/ANL, 50% ANL/anl</td>
</tr>
<tr>
<td>Purple x Purple</td>
<td>anl/ANL x anl/ANL</td>
<td>75% Purple, 25% Green</td>
<td>25% ANL/ANL, 50% ANL/anl, 25% anl/anl</td>
</tr>
<tr>
<td>Purple x Green</td>
<td>ANL/ANL x anl/anl</td>
<td>100% Purple</td>
<td>100% ANL/anl</td>
</tr>
<tr>
<td>Purple x Green</td>
<td>ANL/anl x anl/anl</td>
<td>50% Purple, 50% green</td>
<td>50% ANL/ANL, 50% anl/anl</td>
</tr>
</tbody>
</table>

To perform this experiment, students should identify two plants that they wish to cross and in order to determine the genotype. These plants need to be segregated by rousign the other plants from the bottle. This will help reduce the transfer of pollen from plants other than those being crossed. The pollen is best transferred by using a bee stick. *It is important that a separate bee stick is used for each cross to reduce contamination by other pollen.*

**To determine the genotype of the parents:**

1. Make a hypothesis about the inheritance pattern of the anthocyanin trait. From the F2 data the students should be able to identify that the phenotype is due to a single gene. Students should
generate a hypothesis about the genotype of the two plants they are crossing and also provide alternative outcomes. The idea is to get the students thinking about the various genotypes that can produce the same phenotype.

2. Make a bee stick.

3. Select two plants to be genotyped and label one as the “male” and one as the “female”. We suggest that students work in groups of 2-3 students for this project.

4. Rogue all other plants from the bottle.

5. Transfer pollen from the male plant to the female plant.

6. Continue to pollinate for 2-3 days being sure to only move pollen in one direction.

7. Allow the seeds to develop in the pods.

8. Harvest the seeds from each plant onto a piece of tape. Store the seeds from each plant separately in a coin envelops or something similar.

9. To check the crosses (F3 generation):
   a. Evenly distribute the seeds onto a moist paper towel in a petri dish or plastic bag. Cover the container to retain the moisture.
   b. Place the seeds under the light.
   c. After 2-3 days, the students can score the seedlings for the presence or absence of anthocyanin.

10. Students should use their collected data to provide evidence for or against the hypotheses they generated before crossing the plants.

Life Cycle Extension: Mendelian Genetics and Dihybrid Crosses

Beginning biology students are likely to have encountered Mendelian genetics in other contexts and may well be able to fill in Punnett squares and perhaps even rattle off the segregation ratio of a monohybrid cross. However, Mendel’s laws of inheritance are more fully illustrated by analyzing the segregation of two unlinked traits. The seed stock provided for the Life Cycle Investigation contains two prominent discrete phenotypes; the presence or absence of the pigment anthocyanin (purple vs. green) and yellow-green leaves vs. green leaves.

The seeds provided are of the F2 generation which was produced by crossing F1 plants that are heterozygous for both of the discrete traits. This cross results in segregation of the parental and recombinant phenotypes in a 9:3:3:1 ratio (Table 1). The process for determining the parental genotype (described above) could be used in the context of a dihybrid cross. Of course there will be many more possible genotypes and thus you would want to do more crosses to get a larger population to test. The more individuals you have in the F3 the higher the probability that you will see the predicted ratios.

---

1 http://www.fastplants.org/pdf/seedstocks/f1npsygl.pdf
<table>
<thead>
<tr>
<th>Genotype</th>
<th>Phenotype</th>
<th>Segregation Ratio</th>
<th>7-day-old plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>(-/ANL, -/YGR)</td>
<td>Purple stem, Green leaves (Recombinant Phenotype)</td>
<td>9</td>
<td>![Plant Image]</td>
</tr>
<tr>
<td>(-/ANL, ygr/ygr)</td>
<td>Purple stem, Yellow-green leaves (Parent Phenotype)</td>
<td>3</td>
<td>![Plant Image]</td>
</tr>
<tr>
<td>(anl/anl, -/YGR)</td>
<td>Green stem, Green leaves (Parent Phenotype)</td>
<td>3</td>
<td>![Plant Image]</td>
</tr>
<tr>
<td>(anl/anl, ygr/ygr)</td>
<td>Green stem, Yellow-green leaves (Recombinant Phenotype)</td>
<td>1</td>
<td>![Plant Image]</td>
</tr>
</tbody>
</table>

Table 1. Expected phenotypes and segregation ratio of the F2 generation.
Appendix C

Extension: Quantitative Trait
Selection and Pollination Based on Trichomes

1. Select the 25% hairiest (highest trichome number) plants in your population. This will be your breeding population to create a selected progeny.
   a. How will select the 25% hairiest?
   b. What do you need in order to calculate that?
   c. How will you mark or flag the selected plants?

2. Remove the 75% less hairy plants from the population by cutting their stems at soil level with scissors. In selective breeding for the ‘improvement’ of all kinds of organisms (plants, dogs, fish, etc.) the removal of less desired individuals is called “roguing.”

3. The selected 25% hairiest plants will be pollinated among themselves by you.
   a. Take your bee-stick, and gently collect pollen from anthers of flowers and gently transfer the pollen to the stigmas of the open flowers of other selected plants.
   b. You will do a “mass pollination”, that is, gently collect from and distribute pollen to every open flower. In order to make sure all plants have an equal chance of fertilizing each other, you will need to touch each flower in sequence twice.

4. Repeat the process for 2-3 days among newly opened flowers.

5. When designated pollinated days are finished, remove unpollinated flowers and buds.

6. Count and record the number of pollinated flowers for each plant.

7. After harvesting seeds, plant the next generation, and examine the number of trichomes as you did with the previous generation. Compare the numbers of this new generation with your previous one. Has there been a shift to a higher average number of trichomes?
Appendix D

Hairy's Inheritance
Getting a Handle on Variation

Within the population of Fast Plants there is an observable trait (phenotype) that might escape some students' notice, but which lends itself easily to investigating variation and inheritance. Varying numbers of hairs can be seen along the stem, on the upper and lower surfaces of the leaves, on leaf edges and even on the buds of some Fast Plants (see Figure 1).

The hairs found on the basic Brassica rapa, Fast Plants, constitute a trait that is variable, quantifiable and heritable. Scientists are not sure why plants have hairs although they have some ideas. Furthermore, very little is known about the genetics and inheritance of hairiness.

The number of different genes or alleles that control the number and location of hairs is also unknown. Observing and counting the hairs on Fast Plants will challenge and sharpen students' observational skills and provide them with the opportunity to ask many questions.

Students often measure the height of Fast Plants with a ruler and estimate the actual height in units such as millimeters. Determining the number of hairs is different than estimating height in that each hair is a meristic trait, a discrete unit that can be counted directly.

The expression of the hairy phenotype appears to be under the control of a number of genes and is considered to be a polygenic trait. (poly- Greek word for many).

For these reasons, two Fast Plants stocks, hairless, Hir (0-1), and hairy, Hir (3-6), have been developed for teachers, students, and scientists to investigate the quantitative nature of hairy's inheritance.

The hairy phenotype is described as Hir (3-6). This particular symbol, Hir, is for hirsute (after the Latin for hair). You will also note that since the specific genotype for hairiness is not yet known, the phenotype symbol is used, Hir. As with phenotypes which show a wide variation in their expression, a scale from (0-9) can be used to quantify the phenotype. On the scale from (0-9), 0 = no expression (no hair), 1-2 = low expression (few hairs) 3-6 = intermediate expression (some hairs), 7-8 = high expression (many hairs) and 9 = very high expression (very hairy), (see Figure 2).

This WFPID is designed to give students and scientists ideas for investigating the variation and inheritance of hairs and is presented in "levels" each of which provides students with a given set of concepts and ideas. Moving up a level increases the skill and background requirements of students and teachers.

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Level 1  Observing, Counting and Analysis

For this activity 10 day old Fast Plants are needed. The hairy stock of Fast Plants will work well for this activity unless more variation is desired, then the basic Fast Plant will work.

Students first need to decide how and where to count the hairs on the plants. They can look over the plants and identify where hairs appear on the plant. Students should describe and map with sketches where the hairs are located (see Figure 3).

Next, they need to decide where on the plant they could accurately count the hairs. Younger students may have difficulty counting, for instance, the hairs all around one portion of the stem.

It may be easiest to count the hairs on the edge of the first true leaf. This should be done on or around day 10 in the life cycle when the first true leaf is well developed. Students will need good light coming over their shoulder and a hand lens.

By observing the plant against a dark, contrasting background (construction paper, a classmates sweater, etc.) they can count all of the hairs on the edge of the leaf.

Each student can record the number of hairs at the particular agreed upon location on their plant and then all the data from the class can be incorporated into a frequency histogram as suggested in Figure 4. From observing the graph, students will be able to identify characteristics of the population with respect to the hairy phenotype.

Frequency histograms are an informative method of grouping class data. They may be created with the help of a computer program or simply worked out by hand. For younger students it may be helpful to do this as a group on a large graph (see Figure 4). The horizontal or X axis is the independent variable meaning that it defines the number of hairs counted. Each of the units on the x axis is called a "class" or a "bin" and is dependent on a predetermined class size. The class 0 - 5 denotes that if any student counts 0 to 5 hairs on the margin of the leaf then the student's data are recorded on the graph as a box. The vertical axis or Y axis is the dependent variable.

The size of the variable was dependent on the number of students who's data fell into the predetermined class size on the X axis. If there is more than one student who counted between 0 and 5 hairs then their data point would also be added on the graph as a box. According to Figure 4 twelve students have between 6 to 10 hairs on the leaf edge of their plant. For the frequency histogram of basic Brassica rapa; Fast Plants, see Figure 5.
Level 2
Analysis and Selection of Variation

Figure 5 depicts a frequency histogram of the number of hairs counted on the right margin of the first true leaf in a population of 104 Fast Plants. Notice that the outline of the frequency histogram roughly depicts a curve known as a frequency curve. Do the majority of plants in Figure 5 have few or many hairs? Could you assign a scale rating, Hirl (0-9) to such a graph?

After looking at their graphed data and the population statistics, students could "brainstorm" ideas and develop questions relating to hairiness and inheritance. Questions may include: Is hairiness inherited? How is hairiness inherited? Could hairless or super hairy populations be produced? Could you produce a hairless population?

By choosing the top ten percent of the hairiest plants in the class population as an experimental group and intermitting (pollinating) only those plants, students would be applying what Charles Darwin called artificial or directed selection on the population.

If hairiness were inherited through the combined effects of many different genes (polygenically), one would expect that by repeatedly selecting the hairiest parents for successive generations the number of genes contributing to hairiness in the population would be increased. Would this directed selection increase the population mean (average) for hairiness? Will the offspring of the first intermitting have more hairs on average than the parents? Through how many generations would the students have to repeat the directed selection experiment before producing a super hairy plant?

Further investigations

Students, who ponder these questions and who are trying to understand the inheritance of the hairy trait, will continue to ask more questions. If all the hairy plants from the first (parental) generation are intermitated, will all the offspring have hairs? Will the hairs show up in the same places on the offspring?

Will the progeny of a hairless and a hairy plant have hairs? Will all the offspring of the F1 generation have hairs? If many genes are functioning to produce hairiness, can you keep increasing hairiness?

Is there a limit on the number of hairs that a plant can have? Conversely, if only the hairless progeny mated, how many generations would it take to develop a population of hairless plants?

The environment and phenotype: Environment is ever present in the expression of the phenotype. The degree to which components of the environment, such as light, temperature and nutrition, contribute to the expression of phenotypes is an important part of genetics.

Little is known about the influence of environmental factors on the inheritance of hairiness. Investigation by students could provide insight into the influence of environment on the expression of the hairy phenotype.

Environmental applications:
Students may ask why plants have hairs at all. Do hairs confer an adaptive advantage to Fast Plants? If so, under what conditions? A few scientists have asked the similar questions.
Extension 1:
Consider the shape of the frequency histogram.

Geneticists know that normally distributed continuous phenotypic variation is usually produced by the combined effects of many genes. Such traits are said to be under polygenic control (poly = Greek for many.) Figure 6 is a frequency histogram showing a normal distribution curve. What questions about the inheritance of hairs does the frequency distribution in Figure 6 raise?

Extension 2:
Develop a scale for hairiness (Hir).

Since hairiness is a phenotype that shows wide variation in its expression, a scale from 0-9 can be used to define roughly the range in expression of hairiness, where 0 = no expression (no hair), 1-2 = very low expression (very few hairs), 3-6 = intermediate expression (intermediate numbers of hairs) to 9 = very high expression (very hairy).

By counting the number of hairs in a defined area on the plant, you can convert the 0-9 scale to a graph depicting the relationship of the scaling numbers 0-9 (the independent variable or x axis) and the actual count of number of hairs (the dependent variable or y axis.) What is the relationships of your scale to the number of hairs counted? Is it linear, logarithmic, etc.?

Level 3
Investigations with Hairy and Hairless

As mentioned earlier, the Fast Plants Program has developed two specialized stocks for investigating the inheritance patterns of hairs. Hairless, Hir (0-1) and Hairy (3-6) are ideal tools for researchers and students to conceptualize, hypothesize and experiment with the notions of how a trait or phenotype such as hairs may be inherited. Is hairiness controlled polygenically or by a few genes of unknown effect?

Figure 7 shows the frequency histogram of two stocks from the Crucifer Genetics Cooperative. Parent 1 (P1) is the hairless, Hir (0-1) CrGC 1-54 and Parent 2 (P2) is the hairy, Hir (3-6) CrGC 1-37 stock. Notice the difference in the standard deviation of the Hairy stock compared to the Hairless. What questions about inheritance do these frequency histograms raise?

Figure 7:

<table>
<thead>
<tr>
<th>Hairs on first true leaf margin, day 14</th>
<th>Hairs on first true leaf margin, day 14</th>
</tr>
</thead>
<tbody>
<tr>
<td>CrGC 1-54, F_2 Hairless</td>
<td>CrGC 1-37, F_2 Hairy</td>
</tr>
<tr>
<td>n=94</td>
<td>n=76</td>
</tr>
<tr>
<td>r=8</td>
<td>r=78</td>
</tr>
<tr>
<td>x=0.2</td>
<td>x=31</td>
</tr>
<tr>
<td>s=0.5</td>
<td>s=17</td>
</tr>
</tbody>
</table>
In order to provide more information on the inheritance patterns of these stocks the Fast Plants Program has produced and characterized the F1 and F2 of the these two stocks. The production of the F1 stocks was facilitated by using male sterile, mstD genotype accompanying each of the two parent stocks, see WPFPD Nuclear Male Sterility in Facilitating Crosses.

The male sterile plants in each of the parental stocks appeared at a ratio of 1:1. Removing the male fertile plants from one of the parents before pollen is shed enables strict pollen control in the production of the F1 generation.

By using male sterile on both parents, reciprocal F1 progeny can be produced and examined for potential maternal contributions to the expression of the hairy phenotype. Examples of hair counts for the first true leaf margins, in the F1 and the F2 progeny are depicted in Figure 8 and 9.

Populations such as CrGC 1-71, F1 hairless X hairy, and CrGC 1-73, F2 for hairless X hairy, could be used for many different investigations dealing with inheritance and expression of the hairy phenotype.

Quantifying Gain from Selection, Heritability

To quantify any increase in number of hairs made by selecting and intermating the hairy portion of a population, students would first want to record the number of hairs on each plant in the experimental population (Generation 0) of size = n. Then calculate the average number of hairs on a representative plant = x. The standard deviation is a calculation that described the average amount that individuals vary from a population average and is a useful statistic in helping to understand how the hairy phenotype is inherited.

If students select the 10 percent hairiest plants from the population and calculate the average or mean number of hairs from this subpopulation then the difference between the population and the selected sub-population mean is the selection differential. Seed is produced on the selected plants. Then the progeny from the selected subpopulations are counted for hairs and averaged. The difference between average number of hairs from the original population, Generation 0 and the average of Generation 1 is known as the response to selection. The inherited change in the population due to the 10 percent selection for hairiness is known as the realized heritability, $h^2$, and is the proportion of the response to selection to the selection differential.

$$h^2 = \frac{\text{response to selection}}{\text{selection differential}}$$

Estimates of realized heritability can range from low, < 0.1 to high, > 0.6 and are useful in predicting the rates at which a population can change through selection.
References
WFP Notes reprint, "Getting a handle on variation: quantifying differences in plant height."

Fall, B. S. Fifield, and M. Decker, "Evolution By Artificial Selection A Nine-Week Classroom Investigation Using Rapid-Cycling Brassica." General Biology Program, University of Minnesota, 1995-


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And also see “Hairy’s Inheritance: Investigating Variation, Selection and Evolution with Wisconsin Fast Plants”: http://www.fastplants.org/pdf/activities/hair_var_sel.pdf
Appendix E

Making a Binned Histogram Using Excel

Use a sorted ordered array of the data

- For leaf hairs, count the number of hairs/leaf margin
- Enter them on a spreadsheet for each plant number
- Copy the data to an adjacent column, select the column with the mouse, and Use the Data>Sort command (in ascending order)
- This has already been done on Paul’s spreadsheet
Create list of bin values

- Insert two columns at the end of spreadsheet.
- In one column, title a sequence as Bin histogram.
- The sequence should show the size of the bins to be used – they do not have to be equal, but should be for simplicity.

<table>
<thead>
<tr>
<th>Bin number</th>
<th>Bin histogram</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
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Use the Data Analysis command

- This is one of the Add-ins to Excel.
- To install this Add-in, use the Tools>Add-ins... command.
- The dialog box to the left comes up – check the Analysis ToolPak box, then OK.
Select the Histogram function from the Data Analysis menu

- Once the Add-in is installed, check that it is there with the Tools>Data analysis command.
- Then scroll down to the histogram function and click OK

Select the sorted sequence in the histogram dialog box.

- Click on the side of the input range – the “choose from spreadsheet” icon.
- Highlight the sorted sequence and click the right hand icon again – Excel will automatically enter the range.
Select the Bin range

- Click the “choose from spreadsheet” icon in the Bin Range.
- Highlight your bins in the bin histogram column and click on the right hand icon again.
- The resulting dialog box should look like the one to the left.

Select the output range

- Click on the Output range radio button.
- Click on the left icon.
- Select two columns for the Bin and Frequency values to be entered.
Click OK, then Graph it.

- Clicking OK from the histogram dialog should give you bin and frequency values.
- Select the bin and frequency values with your mouse.
- Graph it- click the Graph icon from the formatting toolbar.
- Select the first (column graph). You can remove the "series 1" legend by unchecking the legend box near the end of the dialog.
References and Resources


Videos:

Gene, Organism and Environment – Richard Lewontin – 1 hour
http://www.youtube.com/watch?v=we4ZzjKxFHM

Role of Environment in Plant Pigmentation – 4 minutes
http://www.youtube.com/watch?v=kMWa3Km_6bk&feature=related

Websites:

Wisconsin Fast Plants home page and links therein: http://www.fastplants.org/intro.php

Background information: http://www.fastplants.org/activities.background.php

Virtual brassica life cycle: http://www.fastplants.org/activities.background.php

Greeenomes: http://www.greenomes.org

Secrets of Plant Genomes Revealed: http://www.plantgenomesecrets.org

The University of Utah’s Genetics Science Learning Center, Learn. Genetics: http://learn.genetics.utah.edu

The University of Utah’s Genetics Science Learning Center, Teach. Genetics: http://teach.genetics.utah.edu